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International Collaboration and Research

IN his report " New Trends in Atomic Research and Their International Significance " Dr. Kowarski, scientific adviser to the European Nuclear Energy Agency examines the changing functions of the public-financed nuclear research laboratories, and then proceeds to itemize specific subjects of semi-applied research where international collaboration, more extensive than is possible by casual personal exchanges, would be advantageous. Initially the national nuclear laboratories in the U.S.A., Canada and the U.K. were created to supply solutions to problems raised by definite national projects; laboratories in other countries have tended to be modelled on their lines. The urgency has now been removed from many of these projects and the honours of national prestige are no longer the driving forces that they were. In this changed climate of nuclear development the functions of the laboratories must also change.

The development of any given reactor system to the point of economic exploitation requires the expenditure of many millions of dollars and commercially this can only be justified if an installed capacity of, say, 10 000 MW can be envisaged at the beginning of the development programme. As a result, only the largest commercial units could make the investment on the scale required but this is not necessarily beyond the capacity of commercial associations, particularly those with an international background, established by normal trade links. But even if the development of nuclear generating plant could be left to such organizations Dr. Kowarski takes it as almost axiomatic that the science cannot be left there; research must continue at a high level to prepare for the future widspread introduction of (and therefore dependence upon) nuclear energy. Such research will be spurred on by the scientific interest of the work and will also carry the promise on the way of what he terms exotic applications, i.e., uses for which there is no conventional substitute such as the propulsion of long endurance submarines.

It is in the field of semi-applied research (scientific effort which is " pure " in its method and " applied " in its aim) that the big nuclear laboratories need to concentrate and make the necessary organizational changes to that end. He suggests that there are three possible modes of evolution of which the most successful will be a change or reversion to the quasi-university functions of seeking novel results. If an establishment attempts to concentrate its efforts upon one particular project followed by a switch to another when the first becomes outmoded, the upheaval created particularly at the level of top leadership will be too great for stability. Some may try to stay on the fringe of practical development projects but this introduces the danger that the choosing of these projects will be influenced by the elements of tradition or novelty rather than result from a proper evaluation of the technical promise. Many examples could be quoted to support this view.

Turning now to those fields of endeavour where an international attack is desirable, Dr. Kowarski cites eight subjects. The first of these is high flux reactors and studies. Although in Europe and in North America there are already available a number of high flux reactors with thermal fluxes of the order of 10^{14}n/cm^{2}s he contends that it is preferable to concentrate the work around individual reactors into special classes of experiments. This is not the practice at present and he acknowledges that there is the counter-attraction that experiments relating to a given project will tend to be performed on a single reactor. This is clearly a more convenient approach when an establishment is concentrating on a given project or when the results are believed to have a commercial security implication.

The second subject is data processing, where it is pointed out that the " programme " is now becoming a fundamental concept of applied mathematics and it may be possible therefore to establish groups specially geared to handle a given class of calculation. The field of reactor physics he limits to the study of steady state and low power kinetics in chain-reacting media, excluding at one end of the scale, nuclear physics proper and at the other, measurements on particular power reactor core systems. The fourth subject for consideration is direct conversion possibly allied to fuel cells. Little work has been done in Europe in this field but this state of affairs must be remedied soon. Advanced types of power reactors other than the Dragon project are put forward, notably the heavy water natural uranium systems and the circulating fuel systems. More general fields are research on materials and components; waste disposal (essentially an international problem) and finally, the miscellaneous exotic applications.

These are subjects of agreed general interest but the organization of international collaboration is a difficult matter. Where there already exists a centre such as Winfrith for Dragon and Oak Ridge for the fluid fuel reactors the problem is simplified but the opportunities for creating organizations from nothing, such as CERN, in the present climate of public opinion are small. Most people would support Dr. Kowarski's view that the setting up of information committees is the easiest approach but the least effective and it is necessary to think in terms of assigning committees which devise plans for sharing tasks and have some power of enforcement.

The European-American Nuclear Data Committee has already gone some way towards laying down a basis for collaboration and the proposal is made that their recommendations should be followed in regard to reactor physics. Additionally it is proposed that an Advanced Proposal Committee be created with a membership of, say, six; a study group on direct conversion and fuel cells and a similar group on data processing be set up; and discussions initiated aimed at international participation in the circulating fuel research at Oak Ridge and the Canadian heavy water projects.

A major problem that Dr. Kowarski does not consider is the functions and status of the existing international

collaboration organizations. Apart from the numerous bilateral and multilateral agreements between countries, for example the U.S.-Euratom agreement, there is Euratom itself and the IAEA, as well as ENEA. These three organizations do in part work together but there is an element of competition between them and this must be resolved before an international approach as ambitious as Dr. Kowarski proposes can produce the desired results.

Nevertheless the report has been accepted by the steering committee of ENEA and a meeting of top level experts is to be convened in October. Meanwhile it is to be hoped that it will receive the serious consideration it deserves, particularly in those circles where a spirit of arrogant isolation is still not entirely dead.

Reactor Merry-Go-Round

IF the negotiations over the London University reactor were to be used as the plot of a play, film or even comic opera it is doubtful if the critics could forbear the use of a few sarcastic comments catechizing the author for the tourtuousness of his theme and his overall lack of realism. Without recapitulating the overture and first acts it will be remembered that after two and more years of havering, DSIR agreed that finance should be made available for three university research reactors in the U.K. These would be located in Scotland, the North of England and London area. There were two applications from London colleges; Imperial College wished to design and build a water moderated type which they had been studying in collaboration with GEC and which was given the name Consort; the other applicant was Queen Mary College who wished to install a Jason to act as a versatile neutron source.

The research reactor committee of the National Institute for Research in Nuclear Science was nominated by the Treasury to advise DSIR on the technical aspects of the various applications. This committee, under the chairmanship of Sir John Cockcroft, approved both the London proposals.

DSIR, however, restricted by Treasury limitations, decided that they could afford only three reactors and had ruled, rightly or wrongly, that the basis of distribution should be geographical rather than purely technical and that the reactors should be so designed and sited as to ensure maximum utilization. This policy was clearly stated in the House of Commons. DSIR, therefore, acting through Sir John Cockcroft, explained their policy to London University and stated that only one reactor could be made available in London which must be shared not only by the two contending colleges, but by colleges of advanced technology, as well as medical and other faculties of the University.

In the meantime the two London colleges had chosen their sites and had them approved by the Ministry of Power. The Queen Mary site was at West Ham, about five minutes from the college, while Imperial College selected a site near Ascot which it is developing for other work.

The University then had available two sites which had been approved from the safety point of view and which, therefore, involved no further safety considerations. Its problem was to select between them and between the reactor types.

DSIR were not anxious to act as sole arbiters and the University agreed to the appointment of an outside committee, whose terms of reference were to select the reactor most suited to the mixed use implied by the new policy.

With these terms of reference the task of the committee was not difficult. Consort was very much a specialized interest of Imperial College, not easily modified to accommodate the work of other colleges and departments; it was conceived with the object of providing a design exercise for advanced students and for work on the actual reactor as much as a source of neutrons for external experiments. Queen Mary's Jason was essentially a neutron source able to feed a number of experimental assemblies simultaneously, each completely decoupled from the others and it gave a flexibility of use not possible in a reactor such as the Consort. The committee of experts were naturally led to the conclusion that a modified Jason was the most suitable reactor for *joint* use.

Meanwhile the University who had been asked by DSIR to select a site appointed another committee under the chairmanship of Sir John Cockcroft to determine which of the two available, the West Ham site of Queen Mary College or the Ascot site of Imperial College, would be the most convenient. For some inexplicable reason this committee ignored its proper terms of reference and reached the arbitrary conclusion that a Consort reactor should be built on the Ascot site—one rather gathers on the grounds that a great deal of money was being spent on Imperial College so why not some more (hence the Ascot site), and the Consort was their reactor, so let them go ahead. Having presented the University with their conclusions, the University, instead of pointing out that the answers given were irrelevant to the questions asked, accepted them.

Apparently the sop given by the committee to the needs of other departments and colleges which they so firmly had been required to include, was the proposal that they should press now for funds for a further reactor to be built in London. This from a committee under a chairman who had previously told the University that it could have only one reactor!

Presumably the next stage is that London University will apply to DSIR for funds to build a reactor which its expert committee rejected and for further funds to build a second reactor which is contrary to its declared policy. However dilatory they may have been in the past this places DSIR in a quite impossible position and no criticism could be levelled against them if they started again at the beginning and another 18 months went by without anything being done.

To complete the confusion Professor Kay, who was largely responsible for determining the specification of the Consort, has accepted an appointment outside the University and it is rumoured he will not be replaced for some time; moreover we suspect that GEC with Hunterston and Tokai Mura on its hands and working at peak to complete its part of UPC's Oldbury tender will not be anxious to divert effort to a project that can scarcely be financially attractive. There is a complication with the Jason too now that Hawker Siddeley Nuclear Power no longer exists, but there are several Argonaut-type manufacturers in the world and it is still possible that AEI, for example, would take over the Jason design.

If a similar capricious approach is made to many other University projects in the U.K. is it small wonder that so many people are greatly perturbed about higher education in this country?

World Digest

Fuel loading of No. 1 reactor at Berkeley nuclear power station was due to start during the last weeks of July and first power (about 10MW) is expected to be generated in December, the full load of 140MW being reached sometime late February or early March, 1962. A similar programme is planned for Bradwell and it is understood that the Minister of Power is not to give permission for loading the first reactors in the two stations until both are ready.

International

Australia, Brazil, Canada, Czechoslovakia, France, India, Japan, Portugal, South Africa, Sweden, U.S.S.R., U.K., and the U.S.A. have been designated as members of the IAEA board of governors for 1961-62. Three of them are new—Czechoslovakia, Portugal and Sweden—and replace Belgium, Finland, and Poland. Also on the board for 1961-62 will be Argentina, El Salvador, Germany, Iraq and Thailand, elected in 1960. A further five members will be elected at the Agency's annual general conference in the autumn to replace Bulgaria, Ceylon, the Philippines, Mexico and Spain, elected in 1959.

An *ad hoc* group of experts has been set up by the ENEA to examine health and safety aspects of the entry of *N.S. Savannah* to European ports. The first meeting was held on June 26 when various problems involved were discussed. A second meeting is convened for some time in November.

The programme for Foratom's first congress, to be held in Paris during September, 1962, has been drawn up. The organizers intend the congress to act as a "follow up" to the OEEC conference held in Stresa, 1959, and from the theme, "Conditions of the Creation and Development of the European Nuclear Energy Industry" and headings of the various sections, this intention should be borne out. Participation in the congress is open to members of the associations that belong to Foratom and organizations and members who are specially invited.

The IAEA receives more requests for technical assistance than it can cope with. This is made clear in a report on technical assistance considered by the board of governors at their recent meeting in Vienna. The report, which covers assistance provided in the form of experts, visiting professors, fellowships, training courses and the use of two mobile radioisotope laboratories, cites the Agency's experience with fellowships as an example of the heavy demand. Up to 1960 they had received 1 500 applications for these but although 1 300 of them qualified it was possible to make no more than 1 000 awards. And a further idea as to the problem can be gauged by a comparison of total funds allocated for assistance in 1959 and 1960. In the first year they amounted to $1 637 000; in 1960 $2 562 000. Both amounts include sums provided under the U.N. general assistance programme.

Formal recognition of Foratom as a consultative body has been made by the IAEA. The board of governors decided at their last meeting to grant consultative status to the organization.

The United States is to make available to the IAEA about $80 000 worth of nuclear equipment for Argentina, Brazil and Israel.

Britain would be welcome as a partner in Euratom, intimated Monsieur E. Hirsch, Euratom President, in his speech before the June session of the European Parliament. Her joining, however, he said, would be "at variance with the interests of Europe if a geographical extension of the Community were to be accompanied by a dilution and diminution of reciprocal obligations." In other words, she would only be welcome on Euratom terms which to many AEA top officials, it is believed, are anathema. One thing that would seem certain, however, if the U.K. were to join and that is she would find a kindred spirit amongst present members in the form of France, who is already rebelling against her colleagues (page 319).

IAEA's 1962 *budget, prepared by the board of governors for approval at the Agency's general conference in the autumn, provides for a total expenditure of U.S.*$8 316 000, 4·4% *more than the total amount budgeted for in the current year. The regular budget, financed from the assessed contributions of Member States, amounts to* $6 261 000 ($6 168 000 *this year*), *and out of this* $885 500 *has been allocated for scientific and technical services and laboratory charges,* $260 000 *for the distribution of information, and* $180 000 *for the holding of seminars, conferences and symposia. Administrative expenses are also allocated from the regular budget. The operational budget, financed from the Agency's general fund which is made up from voluntary contributions, is set at* $2 055 000 ($1 800 000). *Of this amount* $827 000 *is provided for by fellowships and training,* $758 000 *by technical assistance,* $168 000 *for research contracts and* $40 000 *for operation of the Agency's two mobile radioisotope laboratories.*

U.N. Photo

New IAEA Director

THE trend of placing scientists and engineers in top administrative positions instead of lawyers and businessmen—*vide* Professor G. Seaborg as U.S.AEC chairman, Mr. Arnold Lindley as GEC chairman, and Sir William Penney as first U.K.AEA deputy chairman—is continued by the International Atomic Energy Agency by their appointment of Dr. Arne S. Eklund, the Swedish physicist, as their next director-general. He takes over from Mr. Sterling Cole, New York lawyer, whose four-year term of office ends on November 30. As previously observed in *Nuclear Engineering* (November, 1960) there is plenty of scope for improvements in the organization and administration of the Agency over which, presumably, the director-general has considerable control. Whether a man in charge with a different sort of background will in fact bring about any noticeable changes remains to be seen, but at least it would appear that the Agency has chosen a man well qualified to undertake the job. Born in 1911 and educated at Uppsala University, Dr. Eklund was secretary-general of the Second International Conference on the Peaceful uses of Atomic Energy at Geneva, 1958, and until recently chairman of the Dragon project management board, of which he is still a member.

An informal meeting recently took place in Brussels between members of the Japanese Atomic Energy Commission and the president and commissioners of Euratom. They discussed current activities and prospects in the nuclear energy field within the Community countries and Japan. An invitation was extended to the Euratom officials to visit Japan in the near future.

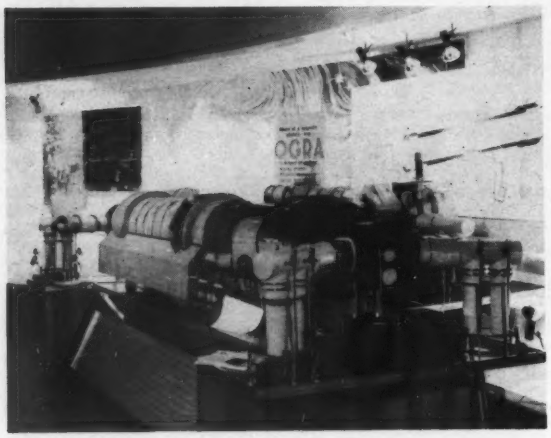
United Kingdom

The committee set up to decide which proposed London University reactor site would be best suited to meet the needs of the various colleges and departments has made recommendations in favour of the Imperial College project at Ascot, while the committee investigating the best reactor type has found in favour of the Jason type as planned for the Queen Mary College. The net result is likely to be more delays in finalizing decisions and it may now be late 1963 before London has a research reactor in operation. (See also page 316.)

Implementation of the Anglo-U.S.S.R. agreement (see last month's "World Digest") begins at the end of July with a visit to AEA establishments by a team of Soviet physicists.

Still No Decision on N-Ship

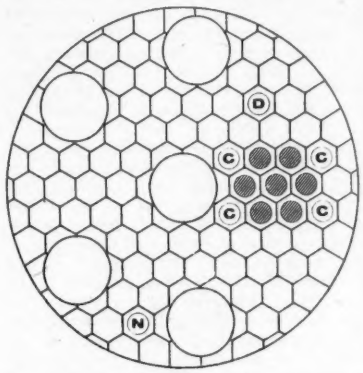
THE Minister of Transport, Mr. Ernest Marples, told the House of Commons on July 13, during a debate on shipping and shipbuilding, that he hoped, but could not promise, to make a statement about Britain's policy on the building of a nuclear ship some time before the recess (late July). Earlier in the debate, Mr. Willey, Member for Sunderland, commenting on the AEA annual report, said it appeared that the experiment in nuclear propulsion had been written off as a failure. As observed in our review of the report on pages 322-324, the AEA have certainly given no indication of any practical steps that could be taken to realize a ship project, concluding that development work on existing reactor systems would be too great to undertake. It has been suggested in some quarters that Britain is delaying a decision until the OEEC make up their minds about their proposed ship project. The two working parties established by the ENEA marine propulsion group to study the economics of various reactor systems and the possibilities of a joint European ship (*Nuclear Engineering*, May, 1961) are scheduled to report to the group on September 15. The group will then in its turn make recommendations to the ENEA Steering Committee, which will then report to the OEEC council.



A model of the Russian mirror machine, Ogra, on show at the Soviet Exhibition, Earls Court, London. Models of Alpha, fission reactors and *Lenin* were also displayed; a description of the nuclear energy section appears on page 343 of this issue. This Exhibition, which ran from July 7-29, was organized by the Chamber of Commerce of the U.S.S.R. in conjunction with Industrial and Trade Fairs, who were responsible for organizing the British Fair in Moscow.

Belgium

BR-2 went critical on June 30 and was formally brought into operation at a ceremony on July 6 attended by the Belgian Prime Minister and Monsieur E. Hirsch, president of Euratom. The reactor was loaded with seven Sylcor 90% enriched uranium fuel elements and five control rods arranged in the manner shown in diagram. Unoccupied channels in the core were filled with beryllium plugs. Counters placed in the position "D" and outside the reactor vessel recorded measurements of 300 and 400 c/s respectively. Cost of the project is estimated at between $18-20 million, not £18 million as inadvertently stated in *Nuclear Engineering*, July, 1961, page 277.



C. control rods; D. counter; N. neutron source.

Non-Commonwealth companies are to be permitted to become members of the DSIR research associations under the terms of a new policy announced in DSIR's "Research for Industry 1960." They will not, however, be able to vote at the annual general meeting or be represented on the Council of the association and before they can join permission has to be obtained from the Department. A further condition of their entry is that all members of the research association they wish to join must be given an opportunity for opposing their membership for commercial reasons.

It is not very long now when the CEGB will have to decide whether to select a concrete pressure vessel design for Oldbury—tenders are due in the middle of August. In the meantime research on the use of concrete for pressure vessels is being undertaken by the Building Research Board of DSIR in conjunction with the U.K.AEA. The Board's recently published report for 1960 reveals, for instance, that investigations are being made into the effects of irradiation on the behaviour of prestressing steel. Special equipment has had to be devised for measuring stress on wires while they are exposed to radiation inside a research reactor. Tests have also had to be made on the effects of elevated temperatures on the steel, the results of which have application outside nuclear engineering. Investigations have continued on the properties of large concrete masses such as encountered in reactor shielding and special studies have been made on the Nimrod, 7 GeV synchrotron, magnet supports.

The Harwell MTR reactors are to be supplemented by a zero energy reactor, Daphne, with a core simulating Dido and Pluto. It will be used for assessing the effects of reactivity on experiments before being inserted into the test reactors. A table of AEA reactors under construction and in operation is given on page 323.

Argentina

Another uranium deposit has been found in the province of Chubut, 200 km from Rawson in the Buenos Aires hinterland, it has been announced by the Comision Nacional de Energia Atomica. Current mining activities are largely centred in the west.

Canadian Critics Partly Assuaged

GREATER participation by Canadian industry in nuclear research and development is urged by the House of Commons research committee established for investigating the activities of Atomic Energy of Canada Limited and other state enterprises (see last month's "World Digest"). They also recommend the setting up of a feasibility study into the economics and engineering of a uranium enrichment plant supported by the Canadian uranium producers. To some extent the committee's recommendations and findings will assuage critics of AECL who feel the company have been playing a too dominant rôle in the Canadian nuclear affairs. In fact although the committee in their report continually commend the AECL for the way it has carried out its work they somewhat endorse this view by their approval of AECL's decision to retire from nuclear power plant construction when the NPD-2 and Candu projects are completed. The committee, incidentally, urge the speeding up of these projects. Yet another recommendation of the committee is a study into heavy water production. On the question of radioactive waste disposal the committee express concern at the absence of any international agreement.

Canada

The House of Commons research committee investigating the activities of the Eldorado Mining and Refining, as well as of AECCo. (see separate panel), have recommended that in view of Eldorado's functions as the Government's purchasing and sales agent for uranium and as contract allocating body a thorough study of its involvement in the competitive mining field should be made.

Denmark

The Alpha project—a design study by Danatom for a nuclear propelled 65 000 ton tanker using a PWR—like the Beta and Gamma projects referred to in "World Digest" last month, is to be revised. The new study will not, however, be completed in time for consideration by the ENEA working party on marine propulsion which has, however, noted the findings of the original study.

France

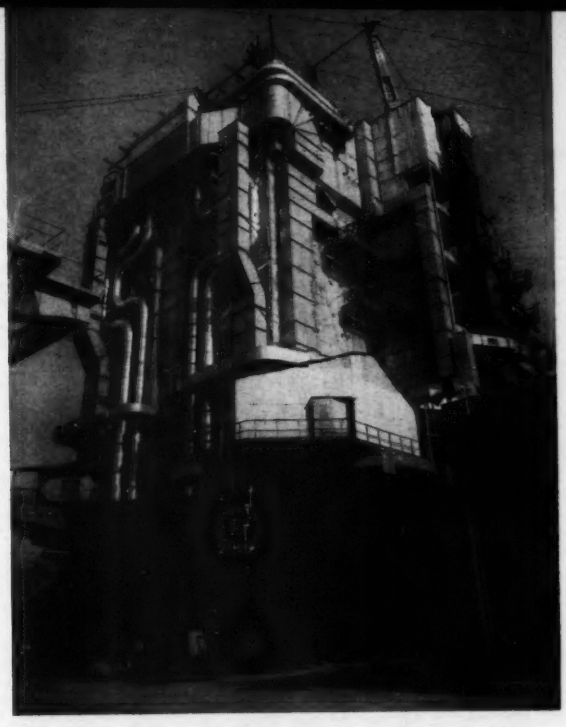
Leading scientists and engineers from CEA will lecture on nuclear energy subjects at the French Exhibition in Moscow, August 15-September 15. There will also be a series of films showing French progress in the various fields of nuclear technology.

West Germany

Two American and one German company have been engaged by Bewag, the West Berlin utility company, to conduct a design study on a 151 MW closed cycle PWR station. The companies are Westinghouse and Kaiser Engineers and Constructors, who will co-operate on the reactor, and Siemens-Schuckertwerke, who will design and engineer the conventional part of the plant and be responsible for the overall design. The study is scheduled to take six months and will be carried out simultaneously in the design offices of the three companies. The study, according to Mr. R. L. Jeans, a vice-president of Westinghouse, will serve as the basis for a proposal to build the plant under the proposed second round joint U.S.-Euratom power programme. So far this programme, which covers reactors to be completed by the end of 1965, has met with little enthusiasm mainly due to the American insistence that components should be bought in the States and disagreement over fuel supplies. It is expected that the U.S. will change its policy on the latter point.

A partial loan of DM18 million has been granted by the Bundes Ministry to the BBC-Krupp reactor group for a design study and experimental work on a 50 MW(e) HTGR. The study and preliminary work are scheduled to last about three years and another three years will be allowed for construction and test operation of the reactor, which will cost a total of about DM25 million.

The Achema seems to be no longer a chemical exhibition, writes a correspondent, but more of a physical show. Stands at the 1961 Achema at Frankfurt, June 9-18, devoted to chemistry and chemical products pure and simple, were few in number. On the other hand 170 companies showed instruments and accessories for the nuclear industry. Overall then, everything apertaining to the nuclear field could be seen, ranging from fuel elements to reactor models.



View of EDF-1 at Chinon with part of the first course of the containment sphere erected.

An order for 32 fuel elements for the swimming pool reactor at Geesthacht has been placed by GKSS m.b.H. with NUKEM. The elements will be MTR type aluminium clad U-Al alloy containing uranium enriched to 90% U^{235}.

Ghana

The installation of a research reactor has been considered, according to the IAEA Technical Mission that visited West Africa earlier this year (see page 321). It is likely that the first reactor eventually to be installed will be a Russian model, Ghana having a treaty with the Soviet Union.

Iraq

The Soviet Union is to supply a VVR-S 2 MW tank type reactor for installation at the Tuwaitha Atomic Centre, Baghdad. Similar reactors have been supplied to Poland, East Germany, Czechoslavakia, Hungary and Yugoslavia. Russia is also to build, equip and operate a radioisotope laboratory.

Lebanon

The Lebanon has been accepted as a member of the IAEA and thus becomes the 75th member State.

Netherlands

A joint design study on a 50 MW BWR plant is to be undertaken by General Electric, of America, and N.V. Samenwerkende Electriciteits-Productiebedrijven (SEP), the utility company of Arnhem. The study will be carried out at San Jose.

Co-operation from the U.S. in the Kema Suspension Reactor Test project was forecast at the Rome Nuclear Congress by Mr. Ulysses M. Staebler, senior assistant director of the AEC division of reactor development. In a paper on thorium fuels he said that the laboratory work still being carried out at Oak Ridge on suspension and pellet fuels was related to the Kema project and close co-operation was anticipated. Dutch reaction is that the suggestion is premature.

France and Euratom

DESPITE French opposition the Euratom Council of Ministers at their meeting in early July decided to provide financial aid to the tune of $19 million to the Sime, Senn and Sena projects. At the same meeting they amended the provisions of the research and instructional programme covered by Article 215 of the Euratom Treaty so as to enable participation in "several" instead of "three" high power reactors, thus ensuring the possibility at a later date of giving aid to at least a Dutch and a German project. The French argue that aid should be given to pure research projects and not what are virtually industrial plants. They also object to participation in the first three projects because they are based on reactor types developed outside the Community. The majority view is that these particular projects will in fact provide considerable information and experience useful to the Euratom's research and development programme, the aim of which, they point out, is to bring about economic nuclear power as soon as possible. The weakness here, in the French view, is that the Euratom Treaty is not clear enough in its definitions, a feature which many see as a strength of the Treaty. The French might eventually get their own way as there are certain aspects of Euratom policymaking which require unanimous voting, among them changes in the amount of funds allocated to the initial five-year research and instructional programme. If the scheme for aid to power projects is extended it could well be necessary to increase the present allocation. Some observers see in the outvoting of France on July 3 a danger of her moving farther away from Euratom. It would seem, however, that while the other member countries will go as far as they can in achieving their own aims they would never push so far as to cause a rift. Of the Six France is the most advanced and strongest in the nuclear field.

Poland

An agreement for further co-operation with the U.S.S.R. in the peaceful uses of atomic energy has been signed. It is understood that the Soviet Union will assist in the construction of the gas cooled graphite moderated reactor planned for the Institute of Nuclear Research at Cracow. It would appear that there has been a change in policy as when plans for this reactor were originally announced it was indicated that it would be an all Polish project.

Portugal

An atomic information centre is being established which until the formation of a Portuguese industrial forum will be represented on Foratom. Negotiations were recently concluded by Dr. A. Gibert, general administrator of the Companhia Portuguesa de Industrias Nucleares.

Spain

Spain is very interested in joining Foratom, according to Dr. Jose A. R. Lopez-Rua, head of the reactor section of the Junta de Energia Nuclear, and to this end preparations are in hand for setting up an industrial atomic forum.

U.S.S.R.

More nuclear ships will be built following an assessment of the performance to date of the "Lenin" and a detailed study of various reactor systems currently under investigation, according to Professor V. Emelyanov, Russian atomic chief. The announcement is contained in a scientific journal article ostensibly about marine propulsion but which Professor Emelyanov uses as a platform for airing politically slanted views on the *Savannah* and the lack of civilian shipbuilding programmes in western countries. He maintains that the delays incurred over getting the American vessel steamed up are due to political and not technical reasons and that American industry is only interested in supporting nuclear marine projects for warlike purposes.

U.S.A.

A lithium cooled reactor experiment is to be built for the AEC by Pratt & Whitney for carrying out advanced materials research. The project will cost about $13 million which will be provided from funds reallocated from the cancelled aircraft nuclear propulsion programme (*Nuclear Engineering*, May, 1961).

Mechanical dejacketing of highly radioactive fuel elements was recently successfully carried out at Oak Ridge—the first time the operation has been performed in the United States. It has of course been practised in the United Kingdom for several years now but with magnox clad elements. The Americans have carried out their operation on stainless steel cans taken from the SRE, Santa Susana. Up to now reprocessing of fuel elements has involved dissolving the whole of each element in acid, a method which will incidentally be used by the U.K.AEA for dealing with the AGR elements. Dejacketing will simplify the process.

Plans for *Savannah* Trials

FIRST N.S. *Savannah* reactor tests are expected to be made if not late July then some time during August. Sea trials will follow soon after. Detailed plans are that the vessel will be made ready for sea at the Camden shipyard where she has been built, the reactor loaded and operated at zero power. She will then be moved under conventional power to a specially prepared berth at Yorktown in Chesapeake Bay and the reactor taken to full power and sea trials started. After about two months the *Savannah* will be returned to Camden for final fitting out. What her movements will be after this are not yet known. When she will go on the proposed world voyage, if ever, depends very much on how soon the Governments of countries to be visited can come to agreements over indemnification of the vessel while in port. Health and safety problems involved, it is interesting to note, were recently discussed at a specially called meeting of ENEA experts, their findings presumably to be presented to the September meeting of the steering committee. In the meantime the delays in getting the *Savannah* up to steam are being used by Professor V. Emelyanov, Soviet nuclear chief, as a weapon in the East-West ideological war.

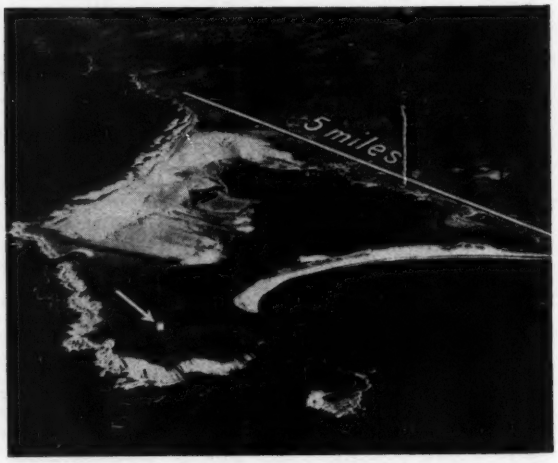
Costs of $60·6 million were incurred during the three months ended March 31, 1961, on non-military reactor projects under design or construction for installation in the U.S., the AEC have revealed. This is $200 000 more than was spent in the preceding quarter and $13·4 million more than the expenditure in the three months ended September 30, 1960.

A 325 MW BWR plant incorporating pressure suppression containment is to be built at Bodega Bay, 50 miles north of San Francisco, for the Pacific Gas and Electric Company. It will be an enlarged version of the 50 MW Humboldt Bay plant now under construction at Eureka, about 200 miles farther north ("World Digest," January and April, 1961). Construction of the Bodega plant is scheduled to start in August, 1962, when the Humboldt Bay plant is due to be completed, and completion date is put as late 1965. It is the largest industry-owned power reactor plant planned to date in the States and P.G. and E.'s decision to go ahead with it is in sharp contrast to current trends in the American nuclear industry. It is believed that the Supreme Court decision on the Enrico Fermi reactor and the AEC price cuts in uranium have had some bearing on it.

The thorium-uranium core for the 275 MW Indian Point reactor plant was recently successfully made critical under test at the Babcock and Wilcox laboratories, New York. It is reputed to be the first large-scale core utilizing a mixture of thorium and uranium oxides ever to have been taken to criticality. A smaller thorium uranium mixture was in fact made critical a week earlier in Atomics International's critical assembly designed for the advanced epithermal thorium reactor (AETR) project ("World Digest," February, 1961). In this test the uranium was of the isotope 233 giving AI the opportunity to claim that it was the first time a U^{233} fuel system had produced a chain reaction in a commercially sponsored facility.

A low power version of the tank type Plum Brook reactor at Sandusky, Ohio, is to be built by the National Aeronautics and Space Administration to carry out tests on experiments before they are inserted into the large reactor. To be completed some time during the first seven months of 1962 it will be known as MUR (Mock Up Reactor).

The U.S. Naval Postgraduate School, Monterey, California, has received AEC permission to operate its AGN-201 at a new site continuously at an increased power level of 20 W(th) and intermittently at 1 MW(th). The reactor was installed in 1957 and up to now the maximum permissible operation level has been 100 mw(th).



Site of the 325 MW BWR power station to be built for Pacific Gas and Electric at Bodega Bay, California (for details see panel above).

A preliminary environmental report on Ogotoruk Creek, Alaska, where the AEC propose to carry out project Chariot has been issued. Project Chariot is designed as an excavation experiment using nuclear explosives and is part of the Plowshare programme. The report draws attention to the effects a large explosion would have on the area and the various biological and meteorological features that would have to be taken into account before a nuclear explosion could be detonated. The report and further information compiled as a result of it will be studied by the AEC together with engineering and other technical data to determine whether the Creek is ultimately a suitable site. Final authorization will, however, be the decision of the President.

Illinois University has modified its Triga Mk II for the purpose of performing pulsing experiments—the first university to do this.

Congress has rejected proposals for converting the Hanford plutonium production reactor for power generation (" World Digest," July, 1961).

The Yankee PWR can now be operated at an increased power level of 485 MW(th). The AEC has amended the operating licence (" World Digest," June, 1961).

Amendments to the operating licence for Dresden have been made. They require inspections of the modified control rod drive mechanisms, control rods and core grid structure. The amended licence is valid until May 4, 1996.

A construction permit is to be issued by the AEC to the Northrup Corporation for a 100 kW(th) pulsing Triga Mk 7 (" World Digest," June, 1961).

As soon as the Supreme Court announced its decision on the Enrico Fermi project (" World Digest," July, 1961) PRDC requested the AEC to extend their construction permit until December 15, 1961. At the time it expired on July 15. Work on site continues apace and on June 9 the first shipment of core subassemblies arrived.

The liability of the Government in nuclear incidents arising from space vehicles and for underground detonations was discussed at the recently held public hearings convened by the Joint Committee on Atomic Energy. The committee were considering two bills introduced for amending relevant sections of the Atomic Energy Act. They also discussed the report on indemnity activities of the Commission during 1960.

Public hearings have been held on proposals for amending the Euratom Co-operation Act of 1958 concerning fuel element guarantees, provisions for liability and indemnity, and a proposal for the transfer of 30 kg of U-233 to Euratom for use in starting up the reprocessing plant for thorium-uranium cycles in Southern Italy (" World Digest," July, 1961). The first two amendments have been introduced in order to smooth the way for implementing the second round U.S.-Euratom nuclear power programme. At the same JCAE hearings, amendments to the Atomic Energy Act of 1954 were also considered. These related to liability for " on site " damage to property, distribution of materials to the IAEA, access of certain employees to restricted data, atomic energy patents, and the use of AEC accident reports in civil actions.

The three satellites, including the "Transit IV-A" equipped with a SNAP generator, which were simultaneously launched from Cape Canaveral on June 29. The "Transit" is the larger of the satellites. More pictures and a description of SNAP apparatus is given on page 328.

IAEA Report on West Africa

ALTHOUGH none of the four African countries visited by an IAEA preliminary assistance mission during March and April has any immediate need for nuclear power, the mission have recommended that developments in this field should be closely followed by the countries concerned. The mission found that in the four countries—Ghana, Dahomey, Liberia and Nigeria—there was plenty of scope for the application of radioisotopes in agriculture and in two of them—Ghana and Nigeria—recommended their introduction for medical applications. The mission recommend geological surveying for uranium and other nuclear materials. In Nigeria, Ghana and Liberia it was found that the future power needs will largely be met by the hydro power schemes; in addition, Nigeria has abundant oil and natural gas sources. It is felt that Ghana, because she has not such resources, should keep the economic potentiality of nuclear power under review, while Nigeria might find it profitable to study the possible uses of small reactors in remote areas. In Dahomey, where present electrical needs are met from thermal stations using imported oil, it is forecast that the country's power requirements in the foreseeable future are not likely to exceed 10 MW. All the same it is felt that nuclear power should not be neglected, particularly as the country's development had hardly started and there was no exploitation of fossil fuels. Nuclear energy matters in Ghana are handled by the National Research Council. In view of the country's radioisotope programme, however, the mission feel that it might be desirable to designate responsibility for the control of import distribution and safe handling of radioisotopes to the appropriate Government department or office.

Correspondence

Snap Core Loadings

Sir,—In your interesting review of U.S. activities in the October, 1960, issue, you indicated on page 463 that " Snap-2 and 10 will use slightly under 3 kg of enriched uranium."

In other publications, one reads that the core of Snap-10 has a volume of around 4 litres. If these figures are right, the mean density of the core would be less than unity, which is impossible.

I suspect that the figure giving the uranium weight is the one in error. It would be interesting to know whether this is in fact the case or whether the words have been misunderstood.

G. Parreins,
Commissariat à L'Energie Atomique,
Centre d'Etudes Nucléaires de Saclay.

Sir,—The core loadings of Snap-2 and 10 are correct as originally stated. The first sentence of the paragraph containing the details of the uranium loading describes the fuel elements as being zirconium-uranium hydride. In addition there are structural materials and coolant volume which were not discussed in the article.

G. M. Anderson,
Lt.-Col. U.S.A.F., Chief, Systems for Nuclear Auxiliary Power Branch.

Correction

The tabulated data on instruments for radiation measurement which appeared in the July issue contained an incorrect reference to dosimeters made by R. A. Stephen and Co., Ltd. The company point out that their dosimeters are 0·6 in diameter and self-reading.

U.K.AEA Seventh Annual Report

THE seventh annual report of the Atomic Energy Authority was presented to Parliament on July 10. As usual no details are given of the Authority's operating budget and it is not possible therefore to analyse expenditure in terms of the various activities. Estimates for 1961-62 which were presented to Parliament in February provide for a net expenditure of £78 071 000 (including a sum of £6 211 000 for the NIRNS) as compared with a total of £93 293 000 for the previous 12 months. The fall of over 16% arises from a decrease in gross expenditure of just over £7 million resulting from reductions in uranium purchases, the completion of certain capital works and various economies allied to an increase in income of just over £8 million. Overall receipts amounted to £21 million during the year, including £5 million for the sale of electricity to the CEGB; proceeds from the sale of 12 000 tons of nuclear quality graphite (the Authority buys Grade A at roughly £400/t and Grade B some £20-30/t cheaper); £1·3 million from the sale of radioisotopes; £90 000 from licences granted under patents; £300 000 from consultancy services to the CEGB, SSEB, Agip Nucleare and the Japan Atomic Power Company; £64 000 from fees to the Authority's schools. The bulk of the balance arises from the sale of fuel elements, as the first charge for Berkeley No. 1 was delivered in the year under review and also part of the first charge for Bradwell No. 1. Advance payments made by the CEGB totalled £6½ million. The Authority sells fuel elements for the Dido type reactors Hifar and DR3 and also reprocesses the irradiated fuel. A quantity of fuel elements have also been supplied to the Land Nordrhein-Westfalen for use in the Merlin type reactor at Julich. Capital assets of the AEA are now valued at more than £500 million.

The Authority's eight reactors at Calder Hall and Chapelcross have continued to perform impressively and have supplied more than 2 000 GWh of electricity to the country's grid system as well as fulfilling their main function of plutonium production and providing a valuable test facility for large-scale development work in aid of the civil programme. Improved efficiency has been achieved by increasing the thermal output of the reactors, by raising the maximum fuel element temperature and also reducing the down time. The thermal output from each reactor has been progressively raised since 1956 from about 140 MW to the design figure of 180 MW at the end of 1957 and now to something approaching the limit of 220 MW. Modifications to the turbo-alternators have become necessary to enable the excess steam to be utilized and these will be completed over the next 18 months. Further surplus steam will be used at Calder and the chemical plants for space heating on the adjacent Windscale site. The first fuel change on Calder No. 1 occupied a time of 11 weeks but careful attention to organization has now reduced the operation to a period of four weeks only.

A number of important experiments have been conducted in the Calder reactors including a test designed to check the safety aspects of the civil stations by irradiating fuel elements to an average exposure of 1 000 MWd/t. This was calculated to simulate in several important aspects the operational characteristics of Bradwell and Berkeley and tests were carried out on the control system to determine the practical implications of the positive moderator temperature coefficient. The results obtained confirmed theoretical predictions and raised no new problems of safety. A number of elements have been irradiated to considerably higher dosages and although one may feel less enthusiastic than the report at the record of 2·3% failures quoted for a group irradiated to over 2 000 MWd/t, the fact that some fuel elements have already successfully exceeded the 3 000 MWd/t mark is more encouraging. Work is now in hand, and should be complete by the autumn, to establish the degree of thermal cycling likely in the civil reactors; an excessive amount can cause cracking of the magnox cans.

Time taken to recharge a Calder reactor has been reduced from 11 to 4 weeks.

Modifications to the chemical extraction plant at Windscale have permitted the plant, originally designed to handle the fuel from the two Windscale reactors (now closed down), to process successfully all irradiated fuel from the Calder and Chapelcross reactors. Work is proceeding on the construction of the new separation plant and it is now anticipated that this will adequately cope with all the civil station demands up to 1970. Considerable progress has also been made on the treatment of the radioactive wastes from Windscale and whilst the quantity of fuel handled has increased the activity discharge to the sea has progressively decreased.

There is little in the Authority's report to suggest any lack of faith in the advanced gas cooled reactor. At Windscale the AGR should shortly be beginning its final commissioning trials and is expected to go critical at the end of the year. The delays in the construction programme have been ascribed to unofficial strikes, a disease to which the U.K. reactor projects seem particularly prone. For the first time however it is officially acknowledged that the first fuel charge will be mainly of stainless steel clad elements as tests on the corrosion of beryllium in carbon dioxide have shown that at the higher temperatures the rate can be unacceptable. Methods of improving the corrosion resistance of beryllium are being actively studied and the programme anticipates the loading of the cooler channels with beryllium clad elements to begin with, followed by a progressive introduction of these elements to the higher temperatures. In spite of the doubts expressed elsewhere in the country of the intransigence of the radiation induced graphite-CO_2 reaction, the official attitude is one of confidence that this problem can be solved. The report mentions investigations into improved graphites with a low permeability, the possibility of impregnation, closer control of the raw materials used in the graphite manufacturing process and, lastly, work on inhibitors. It is suggested that the surface of the graphite may undergo continuous cycling through the gaseous phase back to the solid but that the mass transfer will be tolerably small; this has, however, yet to be demonstrated.

For the first time also a U.K.AEA report acknowledges that whilst the AGR has the potential of producing power at a lower cost than the Magnox reactors, studies have also shown that the HTR and some forms of water moderated reactors could lead to still further reductions in cost. This is particularly true in the medium and small size reactor ranges and the Authority is now prepared to give some of its attention to these smaller systems. It is unlikely that any decision will be taken before the end of this year as to which system should be pursued in preference to its competitors and a more probable date is the spring of next year. In the same way still no decision has been taken on whether the steam generating heavy water reactor is to be pursued to the point of building an experiment. The report mentions some of the studies it has carried out on this design and draws attention to its agreement with Atomic Energy of Canada, Ltd., for a joint development programme. Particular emphasis is placed upon the design of the pressure tubes and mention is made of a successful design of zirconium stainless steel bond for tubes up to 6 in in diameter. (It is interesting

(Continued on page 324)

THE AUTHORITY'S REACTORS AS AT MARCH 31, 1961

Name	Location	Date of Start-up	Peak Neutron Flux (th) n/cm²s	Maximum Thermal Output	Moderator	Coolant	Fuel	Purpose	Main *Nuclear Engineering* References
Research and Experimental Reactors									
1. Gleep	Harwell	1947	$3{\cdot}7\times10^{10}$	100 kW	Graphite	Air	Natural uranium	Routine graphite and uranium quality testing; research with oscillator; biological irradiations.	May, 1956, p. 72.
2. Bepo	Harwell	1948	2×10^{12}	6 MW	Graphite	Air	Natural uranium	Isotope production and general radiation source.	April*, 1956. May, 1956, p. 74.
3. Lido	Harwell	1956	10^{12}	100 kW	Light water	Light water	Uranium–235	Thermal reactor studies, including shielding.	May, 1956. p. 74; Nov.*, 1957, June, 1957, p. 245.
4. Dido	Harwell	1956	$2{\cdot}2\times10^{14}$	12·5 MW	Heavy water	Heavy water	Uranium–235	Nuclear reactor material studies; isotope production; neutron physics; radiation chemistry.	Jan.*, 1957, p.15.
5. Pluto	Harwell	1957	$1{\cdot}4\times10^{14}$	10 MW	Heavy water	Heavy water	Uranium–235	Nuclear reactor material studies; isotope production; neutron physics; radiation chemistry.	Dec., 1957, p. 513. April*, 1958, p. 141.
6. D.M.T.R.	Dounreay	1958	$1{\cdot}2\times10^{14}$	10 MW	Heavy water	Heavy water	Uranium–235	Studies on nuclear reactor materials.	July, 1957, p. 286.
7. Horace	Aldermaston	1958	About 10^{8}	10 W	Light water	Light water	Uranium–235	To obtain basic nuclear information on Herald.	Aug., 1958, p. 351.
8. Fast Reactor	Dounreay	1959	—	60 MW	None	Sodium potassium alloy	Enriched uranium; plutonium	Development of fast reactor technology (reactor physics, fuel elements and coolant handling).	June*, 1957, p. 229. Jan., 1960, p. 5. Feb., 1961, p. 82.
9. Zenith	Winfrith	1959	10^{8}	100 W	Graphite	None; Nitrogen used as heating gas	Ceramic elements containing highly enriched uranium oxide	Reactor physics investigations for high temperature gas-cooled systems. (Maximum temperature 800°C in core, 400°C in reflector.)	Nov.*, 1959, p. 386.
10. Nero	Winfrith	1960	2×10^{8}	Less than 10 W	Graphite	None	Enriched uranium	Investigations for advanced graphite-moderated reactors; pile oscillator studies.	Nov.*, 1960.
11. Herald	Aldermaston	1960	5×10^{13}	5 MW	Light water	Light water	Uranium–235	Neutron physics; radiochemical and nuclear reactor materials studies.	(Jan., 1957, p. 11. Feb., 1957, p. 66. May*, 1958.)
12. Vera	Aldermaston	1961	—	100 W	None	None	Highly enriched uranium	Experimental studies of fast reactor systems.	April, 1961, p. 134.
13. Nestor	Winfrith	1961	10^{11}	10 kW	Light water	Light water	Enriched uranium-Al alloy	Source of neutrons for sub-critical assemblies.	Nov.*, 1960, p. 506.
Research and Experimental Reactors under Construction									
14. AGR	Windscale	1961	$2{\cdot}5\times10^{13}$	100 MW (28 MW(e) net)	Graphite	Carbon dioxide	Enriched uranium oxide	To study the advanced gas-cooled power reactor system and to test fuel elements for the system.	April*, 1961, p. 151.
15. Hero	Windscale	1961	—	A few watts	Graphite	Carbon dioxide used as a heating gas	Enriched uranium oxide	Reactor physics studies for the advanced gas-cooled reactor system.	April, 1960, p. 149.
16. Daphne	Harwell	1962	2×10^{8}	Up to 100 W	Heavy water	Heavy water	Uranium–235	To simulate Dido and Pluto.	
17. Hector	Winfrith	Mid 1962	3×10^{8}	Up to 100 W	Graphite	Carbon dioxide used as a heating gas	Permanent fuel: enriched uranium aluminium alloy. Central core: variable	Oscillator reactor—reactivity measurements on materials and fuel elements.	Nov., 1960, p. 510.
18. Zebra	Winfrith	1962	5×10^{9} fast flux	100 W	None	None	Uranium–235: plutonium	A flexible system intended primarily to investigate the physics of large fast reactors.	Nov., 1960 p. 511.
Plutonium/Power Producing Reactors (in production)									
19.–22. Calder (2 stations, "A" and "B"; 4 reactors)	Calderbridge	Station "A" 1956 Station "B" 1958	—	200 MW (nominal) per reactor (37 MW(e) net)	Graphite	Carbon dioxide	Natural uranium	Plutonium and power production.	Oct.*, 1956, p. 266. Dec.* 1956.
23.–26. Chapelcross (4 reactors)	Annan	1958 (1st reactor) 1959 (reactors 2, 3 and 4)	—	200 MW (nominal) per reactor (37 MW(e) net)	Graphite	Carbon dioxide	Natural uranium	Plutonium and power production.	June, 1959, p. 250.

NOTE: Zeus was dismantled in September 1957, Zephyr in June 1958, and Hazel in September 1958. Nero was dismantled at Harwell and re-erected at Winfrith in 1960, Neptune ceased operation in June 1959. Dimple was dismantled in December 1960 and is to be re-erected at Winfrith in 1961.

* Featured in "The World's Reactors" series.

(Continued from page 322)

to note that no mention whatsoever is made of the Rolls-Royce research into this system, see *Nuclear Engineering*, June, 1961.) The designs of an exponential and sub-critical assembly were started at the beginning of this year as part of a two-year development programme on the SGHWR and studies on the reactor physics of the system are continuing.

In view of the leading advisory position of the Authority to the Ministry of Transport, the stern comments relating to nuclear ship propulsion would appear to come two years too late. The report concludes that the reduction in capital costs necessary to make nuclear power competitive in the marine field is considerably greater than can be reasonably envisaged through the normal development of any of the existing reactor systems. The final turn-round is the conclusion that further work will be concentrated on more advanced systems which show a better economic potential, such as the high temperature gas cooled reactor (a theme which the U.S.AEC has been promoting for about five years). No hint is given, however, of any practical steps that will be taken in regard to marine propulsion.

Among the new plant the Authority is planning to install is a zero energy reactor Daphne which is being designed and built at Harwell with a core which simulates the two materials testing reactors Dido and Pluto. The zero energy assemblies associated with the MTR and ETR at Idaho Falls have proved invaluable in checking experimental set-ups prior to installation in the reactors proper, and in determining fuel loadings outside the main system. A similar facility is to be provided at Harwell for the two MTR reactors there.

The uranium supply and demand became even more unbalanced during the year under review but in the financial statement stocks are included at their purchase value and only heavy pressure will make the Authority write their value down. The stretch-out agreements are beginning to take effect such as the one concluded with the South African Atomic Energy Board which provides for a reduction of 6 000 tons in the quantity delivered by 1967; this amount is now to be delivered between 1967 and 1970. The agreement also provides for a lower purchase price for the later material. Deliveries from Canada were less than three-quarters of those in the previous year as a result of the 1959 agreement and subsequent adjustments. Reference is also made to the 12 000 ton lot which is at present under negotiation. Indications are that the quantity will not be reduced but the purchase price will change appreciably. The report implies that the subject did not become quite so neglected as previous statements have indicated and suggests that there has been progressive negotiation since the first exchange of letters in 1957.

Little mention is made of the research into the use of high speed centrifuges for uranium enrichment and although the Authority is doing some work in this field there is every evidence to believe that it has a low priority and is not considered to be of top rate importance.

The isotope business continues to expand with an increase in sales of 10% over the year, of which 60% was exported to some 60 countries, the overall shipments involving some 40 000 consignments. The use of radiation for sterilization is beginning to increase, the number of plants now being in double figures. Chief interest is in the sterilization of disposable medical equipment. Large quantities of cobalt-60 for this purpose are being produced, the Authority having built up a stock of about 2 Mc. During 1960-1 some 500 000 c were processed and delivered to industrial and experimental installations.

The Authority staff over the period increased from 38 500 to 40 840 and under pressure from correspondents it has been agreed that a rough classification of the staffing can be published. The proportion of non-military research and development staff engaged on support of the power programme is roughly 15%; that devoted to new reactors, 45%; thermonuclear research, 6% (to increase to 8%); isotopes, 3%; the balance is basic and general research.

Introducing Boron Silicide

by Dr. E. Colton
(Research Division, Allis-Chalmers, U.S.A.)

BORON is the most generally used high cross section material for control rod applications where it is desirable to employ a compound of high boron content. Table 1 compares the physical properties of a number of boron compounds and in Fig. 1 are plotted the boron concentrations found in the more common boron containing materials.

With the exception of the boron silicides all boron based solids undergo severe corrosion in air at 800°C and above, forming amongst other products volatile boric oxide. With the silicides the initial attack forms a thin highly protective boron-silicon-oxygen coating which inhibits further corrosion and leads to oxidation curves of the type shown in Fig. 2. The effectiveness of this protective layer is further demonstrated in Fig. 3 where the relative stability of the silicides can be compared with six other compounds after exposure to stagnant air at 1 370°C.

Boron silicide powder can be handled by the usual metallurgical and ceramic techniques and sintered compacts formed either by oxide bonding or self-bonding. For oxide bonding the powder is first cold-compressed at 20 000 psi or more and then sintered in air at about 1 095°C. The resulting material which has a density of 1·7 to 2·1 g/cm³ requires the outer hard shell to be removed by diamond or carbide tools after which carbide tools can be used to machine to the final shape. Refiring at about 1 370°C causes negligible shrinkage and results

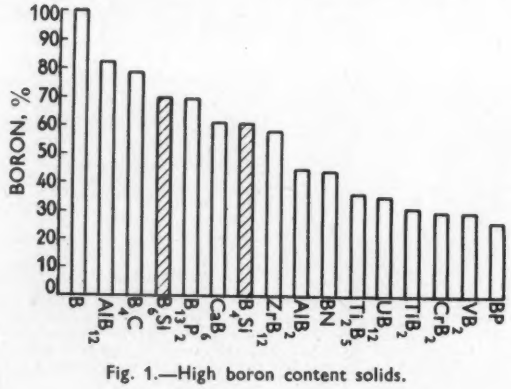
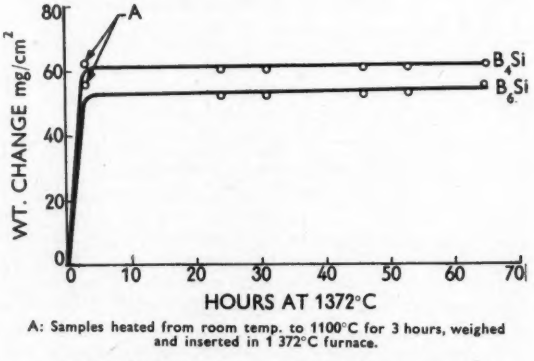


Fig. 1.—High boron content solids.



A: Samples heated from room temp. to 1100°C for 3 hours, weighed and inserted in 1 372°C furnace.

Fig. 2.—Oxidation of boron silicide in stagnant air.

TABLE I
Properties of Some High-Boron Borides

Boride	Wt. % B	Crystal D g/cm³	M.P. °C	Microhardness, kg/mm²	Oxidizes in air severely, above, °C
BP	25·9	2·97	ca. 1 250	ca. 2 500[a, b]	800–1 000[b]
CrB_2	29·3	5·6	1 850	1 800	1 100
VB_2	29·8	5·1	2 100	2 100	prob. 1 100
TiB_2	31·1	4·52	2 900	3 400	1 100
UB_{12}	35·2	5·65	1 500 d.	>800[c]	
BN	43·7	2·20	2 045 d.	soft, moh 2	Solid, 985; powder, 705
AlB_2[d]	44·5	3·19	ca. 1 100	2 400[e]	
ZrB_{12}[f, g]	58·6	3·65	2 680	ca. 1 200[f]	
SiB_4	60·6	2·41–2·47	h	2 400	i
CaB_4	61·8	2·33	2 235	>2 000[j]	
P_2B_{13}[k]	69·4	2·75	>2 300 d.[l]	>2 800[m]	>1 000
SiB_6	69·8	2·39–2·43	See Table II	See Table II	n
CB_4	78·3	2·51	2 450	2 800	540
AlB_{12}[o]	82·7	2·58		2 700[e]	
B	100	2·34	2 300	2 800	1 000

a Popper, P. and Ingles, T.A., *Nature*, **179**, 1 075, 1957.
b Williams, F. V. and Ruehrwein, R. A., *J. Am. Chem. Soc.*, **82**, 1 330, 1960.
c Andrieux, J. L. and Blum, P., *Compt. rend.*, **229**, 210, 1949.
d Felten, E. J., *J. Am. Chem. Soc.*, **78**, 5 977, 1956.
e Cotter, P. G., *Am. Mineralogist*, **43**, (7–8), 781, 1958.
f Post, B. and Glaser, F. W., *J. Metals* 4, *Trans.*, **194**, 631, 1952.
g Glaser, F. W. and Post, B., *ibid*, 5, *Trans.*, **197**, 1 117, 1953.
h No melting point. B_4Si disproportionates into B_6Si above 1 100°C.
i Oxidation tests have been carried out only to 1 370°C. The oxidation curve is similar to that for B_6Si (Fig. 2).
j Mellor, J. W. "A Comprehensive Treatise on Theoretical and Inorganic Chemistry," Longman, Green and Co., New York, 1946, V. 24.
k This boride is referred to as B_4P in ref. b. It has been found to be $B_{13}P_2$ (V. I. Matkovich, *Acta. Cryst.* In. Press, 1960.
l Engelke, J. L., Halden, F. A., and Farley, E. P., WADC Tech. Rept. 56–654, Feb. 1960, 38.
m Work now in progress in our laboratory, by Peret, J. L. and Matkovich, V. I., indicates that $B_{13}P_2$ may be as hard as B_4C.
n Oxidation tests have been carried out only to 1 370°C. See Fig. 2.
o Kohn, J. A. and Eckart, D. W., *Anal. Chem.*, **32**, 296, 1960.

in an extremely hard body. Typical shapes prepared in this manner are shown in Fig. 4.

Oxide-bonded boron silicide has excellent thermal shock resistance partly due to its low thermal expansion coefficient. Plates 2·5 x 2·5 x 0·3 cm have been cycled between 1 095°C and room temperature using an air blast without cracking. They have also been water quenched from the same temperature without shattering.

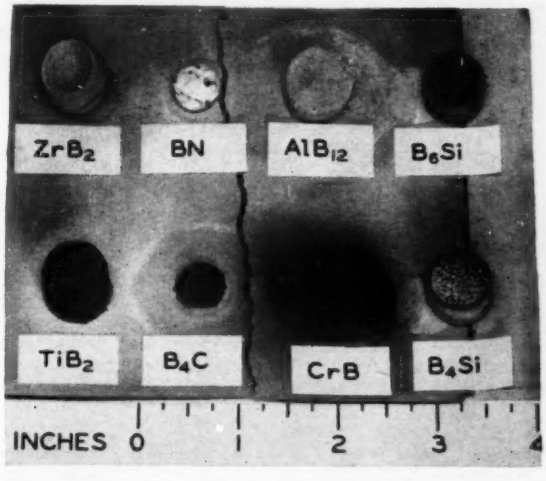
Higher density materials can be formed by self-bonding. The boron silicide powder is compacted by hot pressing and followed by sintering in an inert atmosphere. Densities of at least 2·2 g/cm³ (89% theoretical) can be obtained in this way.

Hexaboron silicide has been the most extensively studied to date and work is proceeding in the Allis-Chalmers laboratories to evaluate fully its properties and uses along with those of the tetraboron silicide. A summary of some of the properties of B_6Si are given in Table 2.

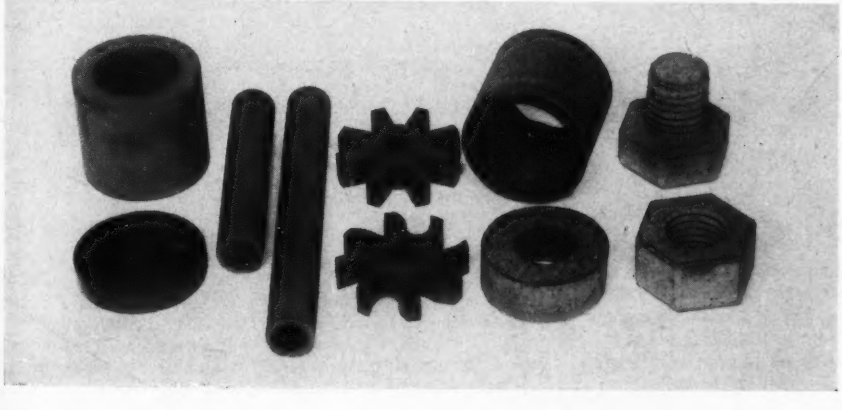
TABLE II
Properties of Hexaboron Silicide (B_6Si)

	Oxide-bonded	*Self-bonded*	*Crystalline*
Theoretical boron content, %		69·8	69·8
Melting point, °C	(a)	1 950 (tentative)	1 950 (tentative)
Specific gravity	1·7–2·1		2·43
Microhardness, kg/mm²			1 950–2 400
Abrasion resistance	~SiC		~SiC
Bending strength, (b) lb/in²	13 000 at 25°C 10 800 at 1 095C°		
Thermal expansion (25–980°C), /°C	$6·3 \times 10^{-6}$		
Electrical resistivity, ohm cm	Insulator	0·01 at 970°C	0·2 at room temp.
Thermal conductivity, room temp., W/cm°C	0·012–0·027	0·11	

(a) No melting was observed in a plasma jet.
(b) For 24-h sintering at 1 370°C.



(Above) Fig.3.—Oxidation of cold pressed borides in stagnant air at 1 370°C for 48 h.



(Left) Fig.4.—Typical pieces machined from oxide-bonded boron silicide.

(Above) Trawsfynydd's Goliath transporting a 350-ton boiler shell.

(Above) Stress relieving furnace for boiler shells, prior to replacing furnace roof.

Building Trawsfynydd's Boilers

OF the nine nuclear power stations built or in course of construction in the U.K., Trawsfynydd in North Wales is the most inaccessible so far as the transport of heavy plant is concerned. Aptly named " across the mountains " Trawsfynydd sets a precedent by not only being the first Welsh nuclear power station but also the first located inland, relying solely on a lake for cooling water supplies.

Recently, through the courtesy of International Combustion, *Nuclear Engineering* was shown some of the problems involved in building the boilers—from shop fabrication, transportation of approximately 150 strakes to the site, to site fabrication and erection.

International Combustion are responsible for a substantial share of the station's plant, including the 12 boilers, main gas ducting, biological shield cooling system, reactor pressure vessel attachments, CO_2 storage vessels and other fabricated equipment.

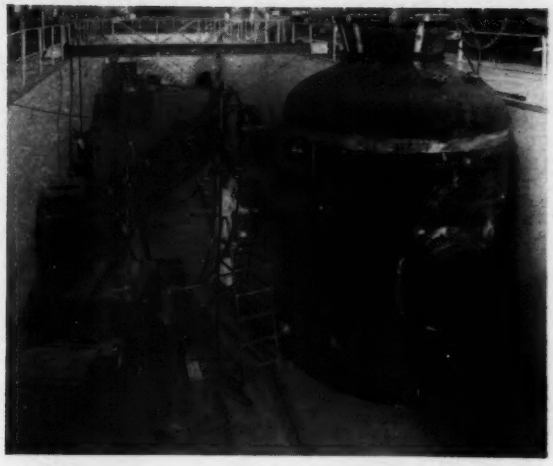
Fortunately, just prior to the award of the contract ICL had opened a new 68 250 ft² heavy engineering shop at Derby and this substantial increase in capacity has enabled the company to install machine tools specifically developed for manufacturing boilers from heavy plant.

The principal items include two vertical presses each of 3 000 ton capacity for bending plates; a 4-column downstroking press rated at 2 000 ton for hot pressing dished ends and segments; automatic welding equipment with a rising boom for vessels up to 12½ ft diameter; a group of three gas-fired and two electrically heated furnaces and a variety of machine tools, the largest being a vertical borer capable of accommodating vessels of up to 25 ft diameter. This list is not exhaustive and the shop can and does call upon other machine tools whenever necessary.

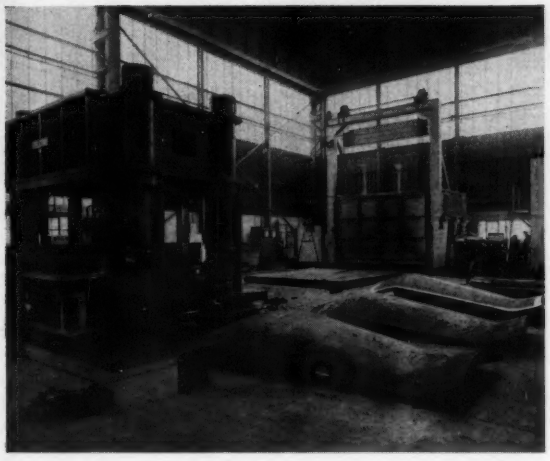
Each of the 12 Trawsfynydd boiler shells is 18 ft diameter, 109 ft 6 in high and weighs 350 tons. To simplify transportation each shell is formed from 12 strakes, the maximum dimensions of these being 18 ft wide and 9 ft 6 in high. As access to Trawsfynydd is restricted to a single rail track a short distance from the site and several secondary roads, an alternative route had to be devised. After a full investigation by CEGB the harbour at Portmadoc was developed. The strakes are transported from Derby to Liverpool with their cylindrical axes vertical (because of height restriction on the road); there follows a short sea journey to Portmadoc where the strakes are unloaded by a 150-ton crane, and the remainder of the journey is accomplished after turning the strakes through 90° and using a special ballasted trailer to avoid risk of the loads overturning on the hills.

On site the strakes are taken to ICL's fabrication shop at the northernmost end of the Goliath tracks. As the photographs on the facing page show the strakes are formed first into sub-assemblies which are radiographed and then welded up to form complete shells. The shell is wheeled outside the shop before being lifted into the stress-relieving furnace by the Goliath. Over a seven-day period the temperature is raised from ambient to 600°C, held there for five hours and then dropped to ambient again. Finally, before erection, the complete shell is subjected to a hydraulic pressure test of 460 psi.

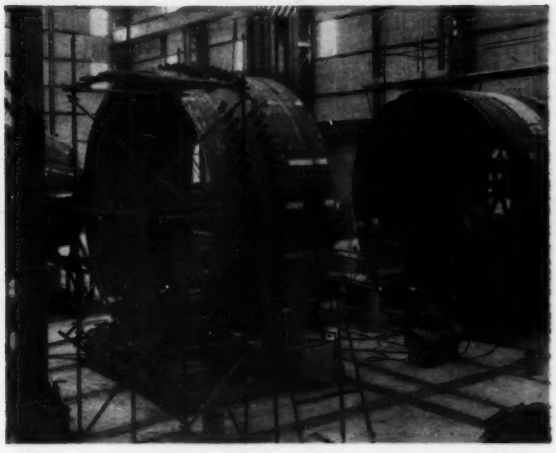
General view of Trawsfynydd reactor building areas with turbine hall on left.



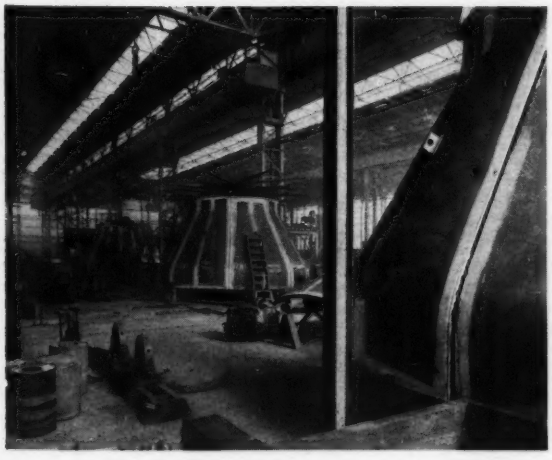
A circumferential seam X-ray using a 400 kV unit. The heat exchanger shown is for AGR.



Petal plates after de-scaling. The 4-column press and furnace are shown at the rear.



Assembly of sets of boiler strakes by circumferential welding on manipulators.



A series of cone ends in semi-welded condition. After full welding these ends are stress-relieved.

Boiler components on the final assembly beds prior to completion of the shell.

ISOTOPE GENERATORS FOR LAND AND SPACE

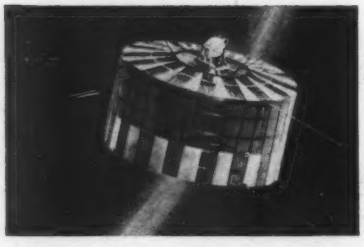
Double Event for the Martin Company

ISOTOPE-FUELLED power units manufactured by the Nuclear Division of the Martin Company, of Baltimore, Maryland, recently scored two remarkable "firsts" within 12 hours, when a weather station transmitter unit, intended for a remote location in Northern Canada, was demonstrated only a short time after the launch of the U.S. Navy's "Transit" satellite, which is fitted with a SNAP generator.

The Satellite Generator

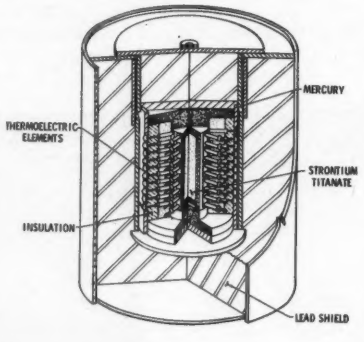
A brief review of the SNAP (Systems for Nuclear Auxiliary Power) programme was given in *Nuclear Engineering* for October, 1960, p. 460. It will be recalled that the series is not confined to any specific type of device, but covers a wide range, including thermo-electric generation fuelled by isotopes, in addition to actual reactor systems, with rotating generators.

Owing to military security, few details are available of the generator used in the satellite. It is said to resemble in principle the original SNAP-3, for which Minnesota Mining and Manufacturing, as sub-contractors to Martin, built the thermo-electric generator. The major advance, however, is the use of plutonium-238 in place of polonium-210 as the heat source, since the half-life is 89.6 years as against about five months. Plutonium-238 is practically a pure alpha-emitter, and being non-fissile, no criticality problems arise; the absence of gamma emission simplifies shielding and handling. Nevertheless, extensive test programmes have been carried out to simulate explosions (including firing of components, preheated to operating temperatures, by rocket at granite targets) to ensure against accidental release of activity. Re-entry of the satellite into the atmosphere will vaporize the entire generator, producing particles of diameter less than 1 ($m\mu$) in. This has been substantiated by tests in a plasma jet.

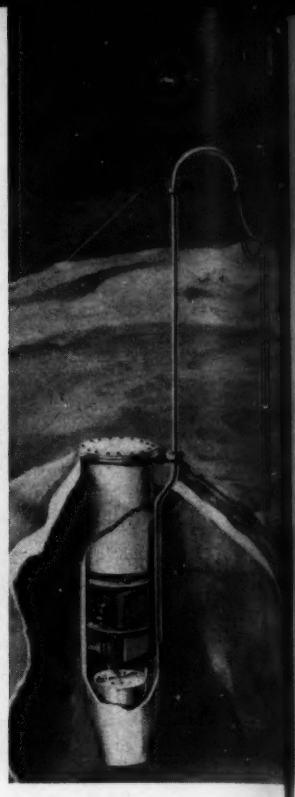


Artist's impression of the satellite.

The generator is approximately 5 in diameter x 5½ in high.



Above, diagram of the weather station generator. Left, assembling the SNAP generator to the satellite before vibration tests.



The weather station generator. Left, lowering the generator unit into the container. Right, cut-away view of the generator on site.

Weather Station Generator

The second thermo-electric generator is intended for stationary work, and size and weight are not of paramount importance. Strontium-90 is used as the source, the activity being 17·5 kilocuries, contained in approximately 1 lb of pellets of strontium titanate, this compound being chosen for its stability (even at its melting point of 3 000°F) and its practically complete insolubility. The fuel is contained in three layers of Hastelloy C alloy, each 0·25 in thick, this alloy having a sea-water corrosion rate of about 0·0001 in/year.

There are 60 pairs of thermo-couples, $\frac{1}{16}$ in diameter x 1¼ in long, disposed in "hedgehog" fashion around the fuel unit. The elements are of lead telluride, the p elements being doped with 1% sodium and the n elements with 0·03% lead iodide. Design temperatures of the hot and cold junctions are 800°F (427°C) and 140°F (60°C) respectively. The output is about 5 W at 4 V, which is converted to 28 V to charge nickel-cadmium cells.

The generator is surrounded by lead shielding 4·4 in thick, the overall dimensions being 18 in diameter x 20 in high. The generator weighs 55 lb without shielding, which weighs 1 625 lb. The outer protection is of stainless steel; the construction is said to be strong enough to withstand a plane crash or explosion.

The generator with its associated equipment is enclosed in a steel housing 26 in diameter x 8 ft high, and is buried in the ground; the total weight of the complete unit is something over 1 ton. It is expected to operate, without refuelling or servicing, for a minimum of two years.

Fig. 1.—Effluent treatment buildings at Bradwell.

WITH the growing interest in the use of radioisotopes for diagnostic, therapeutic and analytical purposes and the advent of the nuclear power stations there is increasing interest in the treatment of wastes of low activity. This presents problems quite distinct from those encountered at the fuel processing plants such as Windscale and at the larger experimental establishments, where there is not only a difference in scale but also in the range of isotopes to be treated. With the smallest laboratories the installation of a treatment plant is probably not worth while. Permissible levels of discharge are governed by local authorities and when the Radioactive Substances Act comes into force they will be set at the discretion of the Minister of Housing and Local Government. The White Paper* which accompanied the presentation of the Bill, in general, recommended a maximum discharge of 10^{-4} μc/ml (concentration of the more commonly used isotopes in the main sewage of the establishment) or if discharge is to rivers, 10^{-3} μc/ml. Unless there are additional limiting considerations, discharge of small quantities of radioactivity to the amounts mentioned above can be flushed to the ordinary drains and larger quantities stored in containers which can then be handled by the national disposal service. For the power stations and the laboratories which expect a regular effluent of long-lived activity, some form of effluent treatment is necessary and some care is required not only in the design of the plant itself but also in the provisions made for piping, ducting, storage and the like.

At the power stations the predominant waste in liquid form will arise in the fuel element cooling ponds from the corrosion of magnox cans, yielding chiefly Zn^{65} and Co^{60}. A normal concentration of 70-80 ppm Zn and 0·5 ppm Co can be expected in the magnox which will lead to a specific activity of about 60 μc/g of each isotope. Until practical operating experience has been obtained it is difficult to give a close estimate of the daily quantity of activity passing into the water but in a 500 MW station 500 mc/d should be an outside figure. The best estimate for Berkeley and Bradwell of the equilibrium conditions is that corrosion products will be formed at the rate of around 100 mc/d, creating an equilibrium soluble activity in the pond of about 700 mc and a concentration in the water of approx. 10^{-4} μc/ml with an element residence time of 130 d.

To minimize corrosion of the magnox the cooling ponds, charged with demineralized water, will be maintained at a pH>11, when the average corrosion rate will be of the order of 1-2 mg/dm²d. Estimation of the rate is not easy as it is dependent not only upon the pH of the pond water but also upon the carbonaceous film formed in the reactor which increases the reaction rate.

This film will be significant only on the elements in the highest (temperature) positions in the reactor and will increase with irradiation time.

In addition to the Zn^{65} and Co^{60} a few % of the activity will come from calcium and iron isotopes, and there may be also contamination with uranium and fission products, although as the general policy is to can any burst fuel elements the fission products contamination of the pond should always be very low.

The maximum amount of activity that can be discharged into the sea from a station is not generally prescribed and will vary from station to station. In practice, activities will be well below even the ICRP's maximum population water concentration for mixed isotopes of 10^{-7} μc/ml, but additionally special conditions in regard to tidal flows, for example, or the concentration of a particular element by marine life will be taken into account. As a result the requirements laid down at Bradwell are more stringent than at Berkeley and the zinc content of the effluent from Bradwell will be minute to ensure that the local oysters, which have an affinity for zinc, do not become contaminated to any measurable extent. In the power stations the policy throughout is to err always on the safe side and the activity in the tidal waters adjacent to the effluent exit from all practical points of view should be negligible.

The majority of the activity in the cooling ponds (around 80%) will be in the form of insoluble products either loose or attached to the magnox cans. Some of the initially soluble activity will also be absorbed on the can corrosion products. The insoluble activity not attached to the can will be removed directly by vacuum sludge cleaning of the pond bottom or by similar methods and by continuous filtering. The sludge so collected will be pumped away, dewatered and permanently stored. The remaining insoluble activity attached to the cans will be removed with the cans on discharge from the pond.

At Berkeley (Fig. 3) treatment of the soluble and suspended products is carried out by circulating 3%/d of the pond water (1 000 gal/h) through a ceramic filter, a cation exchanger which removes the majority of the zinc, cobalt and calcium as well as inactive sodium, and a degassing tower to remove CO_2. Provision is made for diverting the flow if desirable through a mixed bed ion exchange unit before adjusting the pH to the original value of 11·5 with sodium hydroxide and returning the water to the pond.

On regenerating the cation exchanger the activity is brought back into solution and is then fed to a neutralizing tank, where it is sampled to determine the nature of the activity, following which it is either canned for storage or filtered through filter candles and passed to the final delay tanks. Even before entering the estuary the dilution is enormous as the condenser water flow is 21 million gal/h. The degree of dilution following the

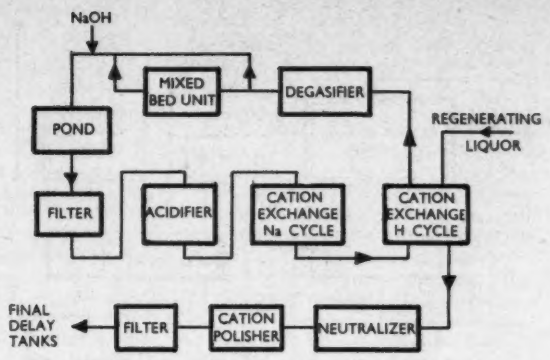


Fig. 2.—Bradwell power station effluent system.

Low Activity Liquid Wastes

* Control of Radioactive Wastes, Nov., 1959, Cmnd. 884.

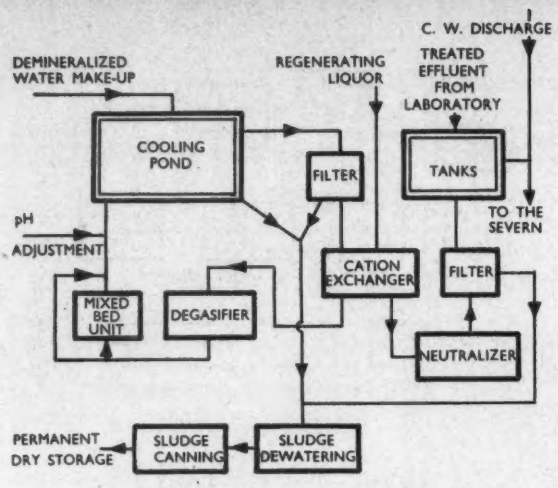


Fig. 3.—Berkeley power station liquid effluent system.

removal of activity in the treatment plant is such that the final discharge should never greatly exceed 10^{-9} μc/ml.

Even so, because of the oyster complications a more complex treatment plant has been installed at Bradwell (Fig. 2). The pond recirculation system after passing through a sand filter to remove the larger particular matter is fed into an acidifier where the pH is adjusted to 7-8. Following this, the effluent flows into a cation exchanger comprising a non-regenerative resin with a specific affinity for zinc working on the sodium cycle. The bulk of the activity will be deposited here and when saturated (after some months) the resin will be stored as a solid waste. The outflow from the exchanger is taken through a second cation exchanger working on the hydrogen cycle, through to a degasifier and back to the pond with the option of passing through a mixed bed exchange unit before pH adjustment, as at Berkeley. The second cation exchanger can be regenerated, the regenerative liquors being neutralized, passed through a further cation exchanger to polish out any remaining traces of Zn and Co, finally to filters and delay tanks from which it is discharged after monitoring into the station cooling water. The total activity discharged to the river will as a result be only a few tens of micro curies per day and the subsequent dilution so enormous that the activity in the river water will scarcely be detectable.

The degree of treatment given to the potentially active washings around the station will depend upon the degree of contamination. This should always be low and a normal route will be similar to that adopted at Berkeley, where washings pass first through oil traps, hold-up tanks and then coarse sand and ceramic filters before being fed direct into the final delay tanks. The hold-up tanks will be monitored and should the activity rise above a prescribed minimum then the effluent can be diverted through the cooling pond treatment system. Additionally, ample hold-up capacity is provided so that should from any cause an unusual high source of activity arise, or a break through the treatment plant occur, water from the tanks can be either recirculated through the system, held up indefinitely, pumped into tankers for treatment elsewhere, or chemically treated on the spot.

Special circumstances governing the siting of the station may require the installation of effluent treatment plant more complicated than those described for Berkeley and Bradwell. At Tokai Mura, for example, it is probable that provision will be made for continuous chemical treatment of the pond water circulation either as an addition or alternative to the ion exchange process. Use will also be made of low-grade steam from the power plant to concentrate regenerating liquors, filter washings and sludge dewatering. At Latina the treatment plant will be similar to Bradwell but provision made for evaporation to eliminate active liquid discharge from the station.

At the Berkeley Laboratories the problem is somewhat different. Activity will arise from a number of sources; a certain amount will be similar to that found in the power station ponds but there will also be an important fraction of fission products and uranium arising from the fuel element examination caves and the research areas. Again, the specific activity is not expected to be high and the volume of liquor to be treated is orders of magnitude different from the power stations. A complicating factor can be the solvents and chemicals washed down the drains and removal of these is as important from a river pollution point of view as the activity. The policy, therefore, has been to provide adequate hold-up tanks and a number of parallel chemical treatment units which will permit the process to be varied with the specific problems in hand.

General washings which are only slightly active, after being held in one of two 1 500 gal holding tanks can be discharged after filtering through pressure sand filters direct into the laboratories outlet tanks (which then discharge into the power station's final delay tanks). More active liquid is directed into one of six 250 gal receiving tanks to which a variety of floc forming and sludge precipitation chemicals can be added. Each tank is treated on a batch process, the settled sludge being pumped away to filter candles from which the dried sludge can be removed and permanently stored, the filtrate returning to the processing plant for recycling. The supernatent from the precipitation tanks is pressure filtered before being passed to 250 gal monitoring tanks, from which it is sent to the holding tanks or re-treated. Filters are cleaned by washing through into two sludge settling tanks, from which the sludge can be pumped to the filter candles.

For the most part conventional chemical treatment will be applicable such as is used on a big scale at Harwell. Here the most generally adopted practice is to use a phosphate treatment in the presence of calcium with iron added as a conditioning agent. Optimum conditions have been found to require a PO_4^{3-}/Ca^{2+} ratio of 1·6 plus 40mg/l Fe^{2+} or Fe^{3+}. The phosphate is added as trisodium phosphate, the calcium when necessary as chloride or nitrate and the iron as ferrous sulphate with the pH maintained at 11·5 by additions of NaOH.

The cost of effluent treatment at power stations and the smaller laboratories is not heavy and at the larger establishments such as Harwell where the effluent farm has been running happily for many years now, operational expenditure is also low. There is nevertheless some incentive for continuing research into the treatment of low and medium activity effluent and at Harwell a comparison pilot experiment (500-1 000 gal/h) is just starting up in order to provide detailed capital and operating cost figures for three separate treatment processes. An additional incentive is to improve the decontamination factor for specific isotopes such as caesium, which in the phosphate process is scrubbed out by passing the clear effluent through columns containing crude vermiculite—an expendable, naturally occurring ion exchange material of adequate efficiency.

A variant on the phosphate process makes use of the ability to precipitate caesium on a copper ferrocyanide floc. Phosphate and iron are added as before in the same ratios and Cu^{2+} and $Fe(CN)_6^{4-}$ as copper sulphate and potassium ferrocyanide. The pH of the effluent is raised to 10·0 by the addition of sodium hydroxide. This high pH reduces somewhat the efficiency of the ferrocyanide treatment but is desirable for

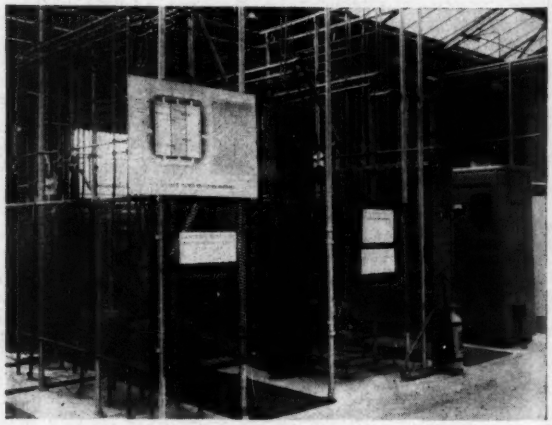


Fig. 4.—Electrolytic cell with ion exchange membranes at AERE, Harwell.

the phosphate precipitation; a final polishing through vermiculite is included.

This system is being compared with two others which make use of ion exchange. In the second process, filters will be followed by two pairs of cation and anion exchange columns. In the past, one of the problems has been the difference in the points of activity breakthrough and conductivity change and for safety reasons columns had to be regenerated before reaching saturation. In the new system, flow is continued until there is a sharp change in conductivity after the second pair (i.e. before activity breakthrough) following which the first pair only are regenerated. These are then returned to a back-up position behind the other pair and flow continued as before. Further increases in efficiency are brought about by the re-use of part of the regenerant and rinse liquors.

The third system under investigation employs the principle of electro-deionization. In this an electric potential is maintained across a number of parallel cells separated by membranes alternately permeable to cations and anions. Alternate cells thus become enriched and depleted in ions. Packing of the cells prevents polarization and decreases the power requirements. The circuit being investigated at Harwell uses a cation and anion cell in series and a mixed bed unit which can be inserted in parallel or in series with the other two.

Construction Materials

In constructing a plant for the treatment of active effluent there are two major points to be watched. The first of these is the build-up of activity on surfaces in contact with the active liquors, iron oxides (and hence rust and scale) being extremely efficient at this. The second is to ensure that surfaces can be simply and efficiently decontaminated in the event of such build-up and that normally dry surfaces following a spill can also be cleaned; surfaces such as untreated concrete are generally inadmissible. In the early days and in the very high activity plants, considerable use was made of stainless steel, and whilst this may be a complete solution, cheaper methods will for the most part suffice. The type of material chosen as the final surface will depend not only on the activity considerations but upon the duties that the particular part has to perform. Good quality well fired ceramic tiles set in an epoxide resin cement satisfy all the conditions for easy decontamination and chemical resistance when subjected to heavy traffic, high point loads and copious hosing. If a monolithic surface is required an epoxide resin mastic provides a satisfactory solution and special grade asphalt may be used if point loading is low and chemical solvents absent. For less arduous duties an epoxide resin paint can be applied or if there is no abrasion a suitable chlorinated rubber paint. For tanks a rubber or plastics lining is used if painting as above is insufficient, and for pipework a thermoplastics or coated steel finish.

At Berkeley, for example, beginning in the charge face area where it has been decided that clean up will be by swabbing rather than hosing or vacuum cleaning, the floors have been covered with an anticorrosive epoxide resin mastic, trowelled on. A gutter is provided between the general charge floor area and the actual charge face of the reactor to prevent spillover. Higher level floors are covered with an epoxide resin paint and the walls painted with chlorinated rubber straight on to the concrete. The structural steel work has been similarly treated, the general practice being to brush on say four coats of paint, each of a different colour, to ensure complete coverage at each application. In the sealed maintenance bay the floor is again of resin mastic and the walls and ceiling chlorinated rubber painted, but in the sub-change room, floors and walls up to dado level are in a ceramic tiling with an acid-resistant mortar jointing, and above the dado level chlorinated rubber painted. The main active change unit is similarly surfaced.

The discharge shaft is something of a special case as it will be largely inaccessible once the station goes into operation and this is lined with stainless steel. The discharge tunnel is, however, in concrete painted with chlorinated rubber. The fuel elements enter a shielded flask at the bottom of the discharge shaft, in which they are transported to the end of the tunnel on a bogie. The flask itself is stainless steel outside but the bogie is painted with chlorinated rubber. Final decisions have not been made as regards the rails and wheels, but non-bearing surfaces may be painted with an epoxide resin and the bearing surfaces left clean on the grounds that the continuous abrasion will prevent activity build-up. The bogie is winched to the central area and the flask lifted and put into the pond, where manipulators remove elements and place them into crates. Crane hooks and chains will probably be painted with an epoxide resin and no attempt be made to maintain the surface of the continually abrading areas. The element crates are of mild steel painted with chlorinated rubber, but investigations are going on into the use of glass-reinforced fibre crates as an alternative.

The same material is being considered for other complex shapes which are difficult to clean, such as stairways, and the coffin bay at Bradwell is finished in a polyester resin with glass fibre reinforcing. The washdown areas at Berkeley are tiled, the tiling being set in a resin bed and the structural steel work will probably be epoxide resin painted, as are the stopcock gates. The decontamination building is surfaced with a suitable acid-resisting asphalt up to dado height and above this painted with chlorinated rubber.

In the effluent plant itself, the ponds are painted with chlorinated rubber and a number of the tanks are of concrete epoxide resin painted inside and chlorinated rubber outside. There are additional mild steel tanks epoxide resin painted and where stirring is necessary, stainless steel impellers are being employed. Pipework is in polyethylene.

At Bradwell, where the cooling ponds are divided into different bays, various surface coatings are being tried to assess their behaviour over the years. The coatings are to include

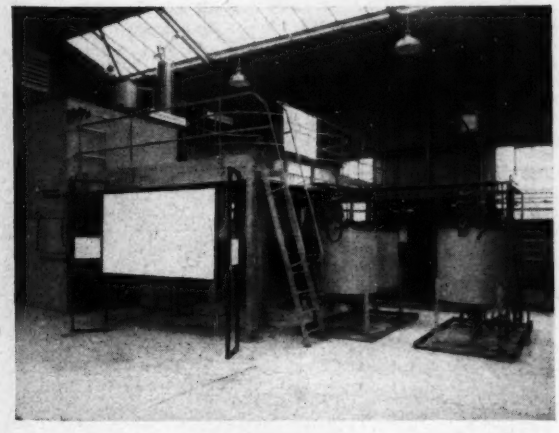


Fig. 5.—Chemical treatment followed by ion exchange (AERE, Harwell).

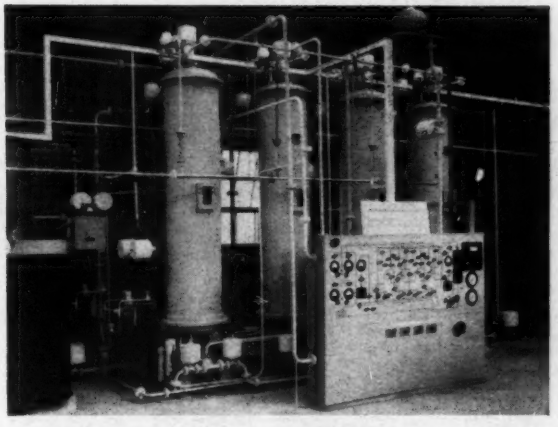


Fig. 6.—Treating effluent by ion exchange only. Rate of flow: 500 to 1 000 gal/h (AERE, Harwell).

chlorinated rubber, neoprene and different qualities of epoxide and polyurethane resins.

For areas which are not to be tiled one of the most critical conditions is a good surface finish whether the final treatment is to be a plastics or chlorinated rubber paint which is preferably "metal-free," i.e., free from certain metals and oxides.

At the Berkeley Laboratories a generally similar practice to that followed in the power stations has been adopted. The entry pond for fuel elements is of concrete rendered with chlorinated rubber, the bearing pads being coated with an epoxide resin, but steel tanks and vessels are painted internally with a bitumastic compound and the concrete hopper bottomed receiving tanks are unlined. Valves (supplied by Saunders) are internally coated with polythene—it is common practice in the Authority to use glass or rubber lined valves from the same manufacturer—sludge pumps are Mono screw pumps for which a common alternative is the Labour diaphragm pump.

The examination caves themselves are finished throughout with an epoxide resin paint, while the moving machinery is either of non-corrosive material or finished with the same paint.

The discharge from the caves is through Vulcathene polyethylene piping, as are the drains in the other sections of the laboratory. These run in a bituminous lined ducting with removable covers, the ducting itself finishing with a blind end and draining to a sump which can be pumped, if necessary, to the effluent treatment plant.

Glass Fuel Elements

PROPOSALS for chemonuclear reactors in which fissile energy is directly employed in chemical synthesis are attracting more and more attention. At the recent Harwell Open Day it was revealed that AERE has initiated a programme of exploratory research to find out the effects of fission fragments on a variety of chemical systems. The fuel for such a reactor might take the form of a dust of small particles of a chemically stable uranium compound or of a very fine glass wool incorporating uranium in the composition of the glass.

A considerable amount of work has already been carried out on this very interesting material and a short while ago two members of the staff of Rensselaer Polytechnic, New York, reviewed current progress before the Section 202 hearings of the Joint Congressional Committee on Atomic Energy.

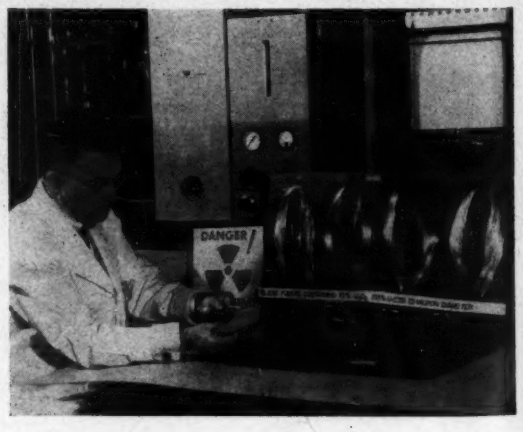
Dr. P. Harteck and S. Dondes told the Committee that successful nuclear chemical conversion directly into chemical energy or for chemical synthesis, requires the utilization of the kinetic energy of the fission products which is approximately 83% of the total energy. As the path length that the fission products travel is so short in solid materials (less than 1/1000 of an inch), and if emission of these fission products is desired to cause excitation and ionization of chemical species, then the matrix for containing the fissionable material must be very thin, in most cases, thinner than a human hair. An ideal material is glass fibre of about 1/10 000-in diameter. In conjunction with the Owens-Corning Fiberglas Corp., natural uranium at first and enriched uranium later was incorporated into glass fibres. The next immediate question was the stability to neutron irradiation. Experiments conducted in the Brookhaven National Laboratory Reactor showed that although the fission products flew out of the fibres, the fibres did not fragment. It seemed as if glass melted over the tracks caused by the emerging particles, a self-healing property. From this initial experience, a host of possibilities presented themselves some of which have been demonstrated by experiment.

The authors went on to say that the manufacture of these fibres calls for the identical techniques and equipment as those in making ordinary glass fibres found in cloth, reinforced plastic, etc. The raw material other than the fissionable and fertile material consists primarily of silica or sand, and a very small amount of soda. Other ingredients in small quantities are added when specific properties are desired in the glass. In no case are materials used which absorb and waste neutrons. Using this technique, glass fibres have been made with uranium contents exceeding 50% by weight. The thickness of fibres produced have ranged in size from less than a human hair to that of broomstraws, the latter considered for power reactors. For power reactor considerations, fibres were coated with aluminium or glass with only a slight modification of technique. Not only has enriched uranium been placed into glass fibres, but also thorium; a mixture of thorium and enriched uranium and, most recently, in conjunction with the Monsanto Research Corp. and Owens-Corning Fiberglas Corp., plutonium, the latter having exciting potentialities.

Although the basic concept was designed for chemonuclear reactors, its application under slight modification soon became evident for power reactors. By increasing the diameter of the fibres, the fission products would not be permitted to escape but their energy turned into heat. As fibres of broomstraw diameter (1/100 of an inch) offer a large surface area, heat transfer to a cooling media is most efficient. Also the temperature difference, as calculated, between the centre and the surface of the fibre, is only about 1 degree, making almost all the heat available for transfer. Fibres containing uranium as presently made have operating temperatures of about 1 000°F. Operating conditions in the region of 2 000°F are in the realm of possibility and 1 800°F has been experimentally achieved. The tensile strength of glass fibres as originally made is about 300 000 lb/in^2, comparable with high quality steel. Under irradiation, this

Fig. 1 (left). — Unirradiated glass fibres (1 micron diameter) containing 10% U_3O_8 of which uranium is 93% U-235.

Fig. 2 right). — 25 micron dia. glass fibres made in a single strand and woven on a bobbin.



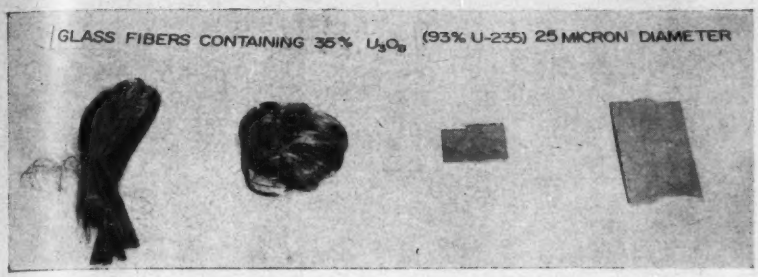
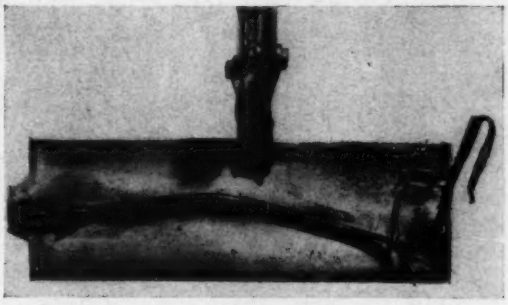


Fig. 3 (above).—Stages in the manufacture of a glass fuel element. The fibres are coated with aluminium, compressed into slabs and coated with pure aluminium.

Fig. 4 (right). — Plate after irradiation for two weeks in thermal flux of 2×10^{13}n/cm² s; attached thermo-couple recorded temperatures from 94°C to 135°C.



tensile strength drops sharply then levels off at about 60 000 lb/in², a strength similar to copper wire. The inertness of glass to chemical attack is well known. Depending upon the diameter of the glass fibre, it is slightly soluble in boiling water, being less soluble the larger the diameter. However, it is badly attacked by high temperature (over 500°F) pressurized wet steam. Other than the corrosive property of water, these attributes indicate usage to power reactors.

In order to determine the possible acceptance in using glass fibres containing enriched uranium as a nuclear fuel element, an effort was directed to duplicating and exceeding the capabilities of an existing type of fuel element. An MTR type aluminium fuel plate was chosen. Enriched uranium glass fibres were coated with aluminium and compressed into a composite, and this was placed between two sheets of aluminium. This sandwich was further compressed into a slab and rolled to the finished dimensions. Specimens irradiated in the BNL reactor for two weeks in a flux of 2×10^{12}n/cm²s were 6 in x 1½ in x 0·060 in in which the fissile matrix was 5½ in x 1¼ in x 0·020 in. No visible damage occurred and metallurgical examination after six months cooling revealed no defects.

In conjunction with the Clevite Corp. and Owens-Corning Fiberglas Corp., further development has proceeded where specimen plates were made which exceeded the specifications of MTR plates which use an aluminium-uranium alloy for the meat in the sandwich. The tensile strength of the glass fibre plays an important role because it reinforces the aluminium. Thus, these plates could be used to a temperature about twice that of existing plates, and could readily replace existing designs.

Another interesting possibility in using glass fibre elements is that they can in essence act as their own filter for radioactive contaminants. In a loop experiment which the authors are conducting at the BNL reactor, high pressure gas flows in a continuous cycle over glass fibre containing enriched uranium. This loop might be considered a small pilot plant for a chemonuclear reactor: the fission products are ejected from the very fine fibres to cause excitation and ionization of chemical species followed by the formation of the chemical products. Under these conditions, the gas stream should be contaminated by all the existing radioactive products of fission. Instead, the gas stream is only contaminated with four components, all volatile, namely, iodine, bromine, xenon and krypton. Of the four, two, iodine and bromine, are removed by their reaction with silver nitrate. This leaves only two inert, rare gases, xenon and krypton, to be separated from the circulating gas by their physical and chemical properties. The capability of self-cleaning increases the value of enriched uranium glass fibre in nuclear technology.

The costs for reprocessing nuclear fuel elements are a major part of reactor costs. In using simply enriched uranium glass fibre or glass coated enriched uranium glass fibre, the reprocessing process begins with treatment with hydrofluoric acid. This attacks the glass producing a gas, silicon tetrafluoride, which may be permitted to escape into the atmosphere. As the glass is composed primarily of silica and urania, this leaves only the unconsumed uranium and the fission products. By further treatment with fluorine gas, uranium hexafluoride can be formed, which may be boiled away to be re-collected and either reused or sent to the diffusion plant. Other fluorides are non-volatile.

Highly satisfactory results have been achieved in the incorporation of plutonium into glass fibres. The aim here was to reduce if not eliminate the radiological and toxicological hazards. Because of these hazards only a few laboratories throughout the country can handle plutonium and then it requires very specialized equipment and precautions. Recently, as much as 20 weight % of plutonium oxide has been incorporated into glass fibres. An important feature is that the glass wipes clean, the usual radiological test for removable activity. This means that the plutonium is tightly held in the glass, will not spread contamination, and may be handled without the rigorous requirements presently specified. Control may be required only for exceedingly fine fibres which are not readily visible to the eye. Although the plutonium ejects alpha particles with high energies, the fibres have not been visually damaged after a seven-month period of storage.

The potential value of using glass fibres containing fissionable and fertile fuels in nuclear reactors has been shown. Still to be accomplished in the research and development fields (other than pure basic research) are primarily radiation damage studies at very high nuclear fuel burn-ups, the production and radiation damage study on a prototype aluminium enriched uranium glass composite fuel element, and radiation damage studies of plutonium glass fibres. These will be carried out in the next six months.

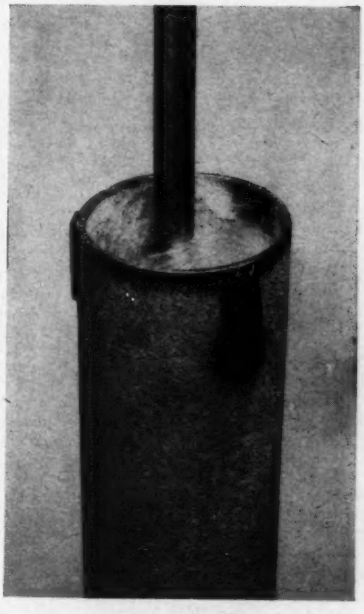


Fig. 5.—The latest fuel element with outer can of fritted stainless steel to avoid compaction of the glass fibres.

Stress Analysis of Rim Reinforced Openings in Pressure Vessels

Part 1.

by R. KITCHING and MRS. J. PERKINS
(The Nuclear Power Group)

WHILE large areas of pressure vessel shells are subjected to stresses which are amenable to simple calculation, important stress concentrations occur where discontinuities arise and where additional loads are applied through necessary attachments. Openings for nozzles and manholes, changes of section such as stiffening ribs and change of general geometry as at the joint between a spherical end closure and a cylindrical barrel come into the first category. Reactions due to dead weight and temperature differentials occurring at supports and at branch openings are included in the second category.

For convenience these problems will be dealt with as they apply to the most common stress raisers, namely branch openings, supports and changes of geometrical shape of shell. The work which follows applies to thin shells only (i.e. where the diameter is greater than ten times the thickness). This means that only biaxial stress fields will be considered, while stresses perpendicular to the tangent plane to the shell at any point will be neglected since they are usually negligible in shells of these proportions.

Design codes (B.S. 1500: 1958 and ASME Boiler and Pressure Vessel Code, Section VIII) give formulæ such that the main shell dimensions may be calculated and the allowable stresses are those which will arise in the main body of a shell due to pressure. Provision for reinforcement at otherwise highly stressed points is made, but it should not be expected (and it is not intended) that the design stress will not be exceeded at these points for all design conditions. Although there is no requirement for the calculation of stresses in the Code, estimates of stresses at important points are made by designers, particularly in the nuclear field, where evidence of safety in plant operation is demanded by the customer. In addition to the design pressure condition, all other conceivable loading conditions must be catered for, including the pressure test and stress relief conditions which will, in general, be more arduous. The acceptance of stresses incurred will be decided in relation to the particular duty involved and these articles do not include any discussion on this matter.

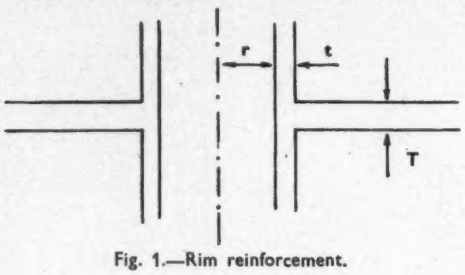


Fig. 1.—Rim reinforcement.

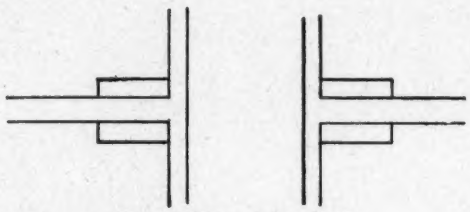


Fig. 2a.—Ring reinforcement.

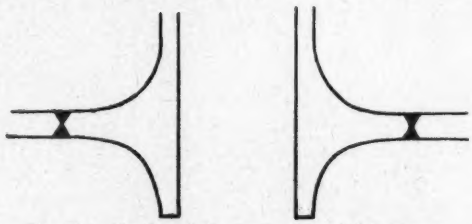


Fig. 2b.—Combined rim and ring reinforcement.

Openings (Rim Reinforced)

Reinforcement of openings may be divided into two classes. Where the branch pipe or duct, itself a thin shell (see Fig. 1), provides a relatively thin rim around the opening this will be termed rim reinforcement. Where the shell thickness is locally increased by pads or by a forging welded into the shell (see Fig. 2a) this will be referred to as ring reinforcement. Normally when this is used it is combined with the reinforcement provided by the branch so that the opening in Fig. 2b would strictly be described as combined rim and ring reinforcement. In this article only rim reinforcement will be considered.

As elastic stresses only will be taken into account the total stress at any point in the region of a branch will be made up of the algebraic sum of the stresses due to all the important causes, which can usually be classified as follows:—

(1) The interruption of a continuous stress field by a change of geometry.

(2) An end thrust on the branch due to pressure inside the vessel.

(3) An end thrust due to the dead load of the pipe system, wind load, settlement, thermal movements, etc.

(4) A bending moment on the branch acting in the longitudinal direction of a cylindrical shell.

(5) A bending moment acting in the circumferential direction.

In the case of a spherical shell the applied bending moment is considered acting in its given direction, and is not split into two components.

Notation

In each case the stress will be expressed in the form of a factor j with a suffix 1, 2, 3, 4 or 5 depending on the cause, while the direction and position of the stress will be indicated as follows:—

j^1 Tangential stress (with respect to the branch centre line) in the shell.

j^{11} Radial stress in the shell.

j Hoop stress in the branch.

With this notation a stress concentration factor in the tangential direction due to end thrust from pressure would be $j_2{}^1$. That due to the same cause in radial direction would be $j_2{}^{11}$.

All factors will be expressed relative to the nominal design stress which in the case of a cylinder would be pR/T, and in the case of a sphere $pR/2T$, e.g. for a branch into a sphere:

$$j_2 = \frac{\textit{Hoop stress in branch due to end thrust effect}}{pR/2T}.$$

Sign Convention

The sign convention which will be adopted regards all tensile stresses as positive. An externally applied compressive load $\bar{P}$ acting radially on a thin-walled shell will produce an inward deflection of the shell which will be regarded as positive, and will create a positive bending moment in the shell giving compressive stresses at the outside surface of the shell and tensile stresses at the inner surface, together with a negative membrane force which produces compressive stresses throughout the thickness of the shell.

Geometric effect ($j_1, j_1{}^1, j_1{}^{11}$)

The biaxial stress field in a plate due to pressure may be represented by:

For a cylinder: $\sigma_1 = pR/T$; $\sigma_2 = pR/2T$.

For a sphere: $\sigma_1 = \sigma_2 = pR/2T$.

If this is interrupted by an unreinforced hole the stress factor in the region of the hole[1] would be 2·5 or 2·0. Reinforcement around the rim will reduce this value and for this reason B.S. 1500: 1958[2] encourages the use of such reinforcement according to the following rule: Referring to Fig. 3 and neglecting corrosion allowances, if the shell thickness T gives rise to design stress at design pressure, reinforcing area A_1 should be at least equal to area removed A_2. No indication is given as to the most effective distribution of A_1, the only limitation being that A_1 must be provided within a diameter $2d$. Effectiveness of the branch metal as reinforcement will obviously diminish rapidly the farther it is from the shell. A limit is thus placed on the distance h to which branch metal can be included in area A_1. This is $(dt)^{1/2}$. A more reasoned assessment has been given by BWRA following their theoretical and

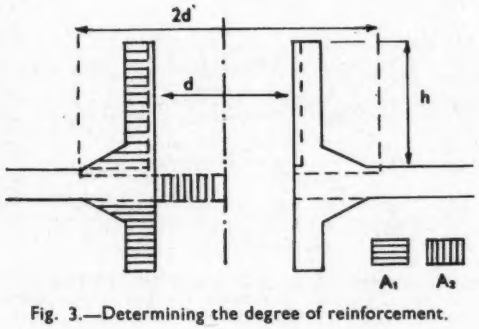


Fig. 3.—Determining the degree of reinforcement.

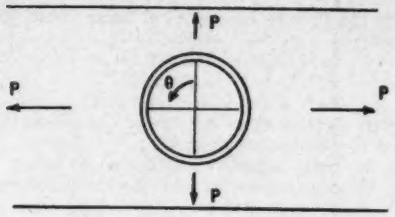
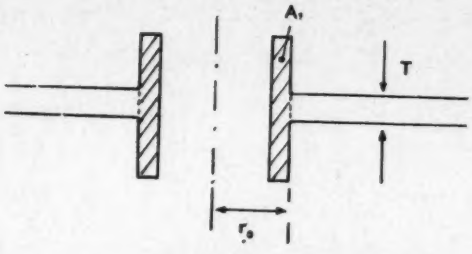


Fig. 4a (above). Fig. 4b (below).



experimental work on this subject[3] which gives the effective height of h as $(rt)^{1/2}/n$ where r and t are the radius and thickness of the branch, $n^4 = 3(1-\nu^2)$ and ν is Poisson's ratio.

For a branch which fits flush to the surface of the shell, the effective height h^1 of the unsymmetrical reinforcement is reduced to $\{(rt)^{1/2}/n\}\{(1+q)/(1+2q)\}$ where $q = (Rt^5/rT^5)^{1/2}$ depends on the relative stiffness of the branch and shell.

In reinforcing an opening it is therefore necessary for the designer to supply compensating metal according to the Code method for calculating effective height, though in checking stresses afterwards he should use the BWRA method.

It will be seen from what follows that the replacement area A_1 is an important concept and we shall use the term "replacement factor" which will be defined as $y = A_1/r_0 T$ where A_1 is now calculated by the BWRA method.

An analysis of stresses around a rim reinforced circular hole has been carried out by Beskin[4] using the elasticity equations in polar form. Any biaxial stress field σ_1, σ_2 is first replaced by a combination of a uniform tensile stress field and a uniform shear stress field,

where $\sigma_1 = P+Q$

$\sigma_2 = P-Q$

For a cylinder where $\sigma_1 = pR/T$ and $\sigma_2 = pR/2T$,

then $P = 3pR/4T$ and $Q = pR/4T$.

For a sphere where $\sigma_1 = \sigma_2 = pR/2T$,

then $P = pR/2T$ and $Q = 0$.

Assuming the circumferential stress in the rim to be uniformly distributed over the area of the rim, and taking the centre line of the branch as the origin, the following equations hold for P acting alone (Fig.4):

$$\left.\begin{aligned}\sigma_r &= a/r^2+2c\\ \sigma_\theta &= -a/r^2+2c\end{aligned}\right\}\ \text{reference 5.}$$

where σ_r is radial stress in the plate,

σ_θ is tangential stress in the plate,

σ_H is hoop stress in the branch tube.

Inserting the boundary conditions, namely:

At $r = \infty$, stresses in the plate are unaffected by the opening

hence $\sigma_r = P$.

At $r = r_o$, forces in the rim and plate are equal and strains along the circumference of the opening are equal.

Hence $2A_1\sigma_H = 2r_o T\sigma_r$

$\sigma_H = \sigma_\theta - \nu\sigma_r$.

The equations become:

$$\sigma_r = \frac{Pr_o^2}{r^2}\left(\frac{2y}{1+y(1+\nu)}-1\right)+P,$$

$$\sigma_\theta = -\frac{Pr_o^2}{r^2}\left(\frac{2y}{1+y(1+\nu)}-1\right)+P,$$

$$\sigma_H = 2P/\{1+y(1+\nu)\}.$$

Repeating the process for the pure shear stress, the initial equations are[6]:

$$\sigma_r = -(b+c/r^4+2d/r^2)\cos 2\theta,$$
$$\sigma_\theta = (b+c/r^4+2fr^2)\cos 2\theta,$$
$$\tau_{r\theta} = (b-c/r^4-d/r^2+fr^2)\sin 2\theta,$$

where $\tau_{r\theta}$ is the shearing stress in the plate and θ is the angle from the direction of the principal stress σ_1.

Inserting the same boundary conditions as before, together with equal shearing stresses around the circumference of the opening:

$$2A_1\, d\sigma_H/d\theta = -2r_o\, T\tau_{r\theta},$$

the equations become:

$$\sigma_r = \left[1+\frac{3r_o^4}{r^4}\left\{\frac{1-y(1-\nu)}{1+y(3+\nu)}\right\}-\frac{4r_o^2}{r^2}\left\{\frac{1+y(1+\nu)}{1+y(3+\nu)}\right\}\right]Q\cos 2\theta,$$

$$\sigma_\theta = \left[-1-\frac{3r_o^4}{r^4}\left\{\frac{1-y(1-\nu)}{1+y(3+\nu)}\right\}\right]Q\cos 2\theta,$$

$$\tau_{r\theta} = \left[-1+\frac{3r_o^4}{r^4}\left\{\frac{1-y(1-\nu)}{1+y(3+\nu)}\right\}-\frac{2r_o^2}{r^2}\left\{\frac{1+y(1+\nu)}{1+y(3+\nu)}\right\}\right]Q\sin 2\theta.$$

$$\sigma_H = -\frac{4Q\cos 2\theta}{1+y(3+\nu)}.$$

Combining the two conditions to obtain stresses due to σ_1 and σ_2,

$$\sigma_H = \frac{2P}{1+y(1+\nu)} - \frac{4\,Q\cos 2\theta}{1+y(3+\nu)}.$$

Maximum values of σ_H occur at $\theta = \pi/2$ giving

$$\sigma_{H\,max} = \frac{2P}{1+y(1+\nu)} + \frac{4Q}{1+y(3+\nu)}.$$

Stresses in the shell at the edge of the rim are

$$\sigma_r = y\sigma_H,$$
$$\sigma_\theta = (1+y\nu)\,\sigma_H.$$

For the particular case of the cylinder

$$\sigma_H = \frac{2(3pR/4T)}{1+y(1+\nu)} + \frac{4(pR/4T)}{1+y(3+\nu)},$$

giving

$$j_1 = \frac{1{\cdot}5}{1+y(1+\nu)} + \frac{1}{1+y(3+\nu)}.$$

For the sphere

$$\sigma_H = \frac{2(pR/2T)}{1+y(1+\nu)},$$

giving

$$j_1 = 2/\left\{1+y(1+\nu)\right\}.$$

For both cases

$$j_1^{\,1} = (1+y\nu)\,j_1$$
$$j_1^{\,11} = yj_1.$$

The variation of these stress concentration factors with respect to the replacement factor y is shown in Fig. 5. This method will, of course, only apply to relatively small diameter openings in comparison with the shell diameter, as one assumption is that the metal surrounding the opening is in the form of a flat plate.

Strictly speaking, it also applies to reinforcement distributed equally on both sides of the shell plate, but in the absence of an alternative simple solution it is used where the reinforcement is unsymmetrically distributed, always bearing in mind that there will be some underestimation.

Unsymmetrical arrangements always give rise to bending stresses, and an analysis has been developed for these stresses in and around a rim reinforcement placed on one side only of a hole in a spherical shell[7]. However, the solution is non-linear with respect to the internal pressure and only applies to the case of uniform tension in the shell. As the principle of super-position cannot be used the method is not sufficiently general to be considered in detail here.

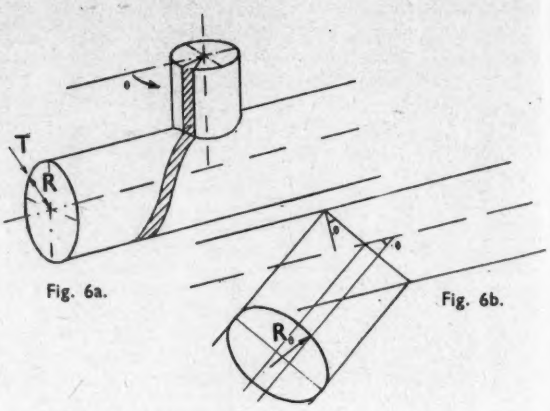


Fig. 6a. Fig. 6b.

If the branch projects at all on both sides of the shell, the shell tends to behave as though it were symmetrically reinforced[8].

End Thrusts (j_3, $j_3^{\,1}$, $j_3^{\,11}$)

The effect of an end thrust on a branch may be analysed in a number of different ways, two of which will be considered.

Beam on Elastic Foundation Method

The equations for the radial deflection of an axisymmetrically loaded cylinder are exactly the same as for a beam on an elastic foundation[9]. A longitudinal strip of the cylinder may be regarded as such a beam with stiffness of the equivalent foundation $\beta_1 = n/(RT)^{1/2}$ being dependent upon the radius and thickness of the cylinder.

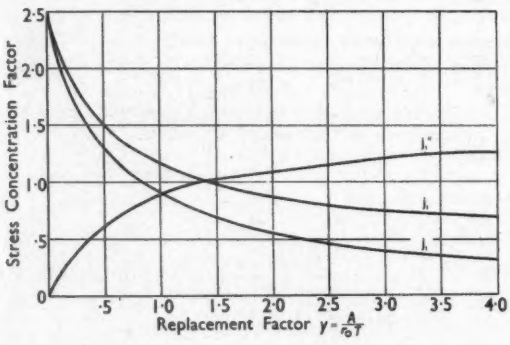
It has been shown that such a strip still behaves in a similar manner even when the loading is not axisymmetrical, provided the variation of load around the axis is not very rapid. This is also approximately true if the strip is not cut longitudinally, but at an angle to the axis[10]. In this case, however, the radius must be modified to that applicable to the strip at the point concerned (Fig. 6).

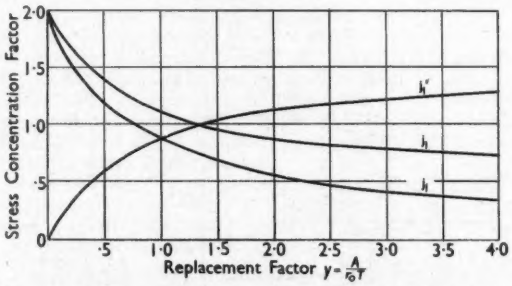
A reasonably accurate analysis can thus be obtained for the stresses arising at a branch opening due to end thrusts using this information. Compatibility at the joint of two beams on elastic foundations is enforced giving boundary conditions by considering strips I and II in Fig. 7(a). Equations are obtained by taking a vertical section (as drawn) through the axis of the branch. Fig. 7(a) indicates a branch which is welded flush with the shell. When it is a through branch (Fig. 7(b)) the strip I is considered as an infinite beam, not a semi-infinite one.

The following relations for flush branches define the boundary conditions stated[11].

Radial deflection and rotation of the shell at the joint

$$\omega_o = -(\beta_0\, M_0 - P_0)/2\beta_0^{\,3}\, D_1$$
$$\phi_o = (2\beta_0\, M_0 - P_0)/2\beta_0^{\,2}\, D_1.$$





Geometrical stress concentration factors for a cylindrical shell. Fig. 5a (left).—Against y for cylinder. Fig. 5b (above)—Against y for sphere.

Nuclear Engineering

DATA SHEET

No. 16. Magnox

MAGNOX A12

Composition—Mg/0·7–0·9% Al/0·007–0·015% Be [1]

PHYSICAL PROPERTIES

Table 1
Coefficient of Linear Thermal Expansion $\alpha \times 10^6$/°C [2]

20°–100°C	20°–200°C	20°–300°C	20°–400°C
25·4	26·2	27·0	27·9

Table 2
Thermal Conductivity kcal/s cm °C [2]

0°C	100°C	200°C	300°C	400°C
0·276	0·288	0·299	0·311	0·323

Density—1·75 g/cm³ at 18°C [3]
Melting Point—647 ± 2°C [5]
Specific heat—No determinations reported but calculations from the heat capacities of the constituent elements give a value varying by less than 0·2% from that of Mg. The values for this element may be computed from :
$Cp = 0{\cdot}244 + 1{\cdot}07 \times 10^{-4} t$ between 18 and 600°C [3]
Cp cal/g °C

RECRYSTALLIZATION AND GRAIN GROWTH

Table 3 [4]
The Strains Promoting Maximum Grain coarsening on Annealing at 400°C for 2 h

Straining temperature (°C) ..	20	100	150	200	250	300
Critical Strain (%)	0·45	0·86	0·8	2·2	2·3	3·0

Initial grain size—0·010 in. Peak grain sizes after annealing ~0·1 in.

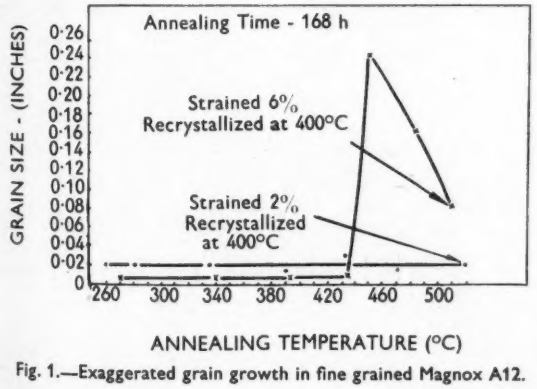


Fig. 1.—Exaggerated grain growth in fine grained Magnox A12.

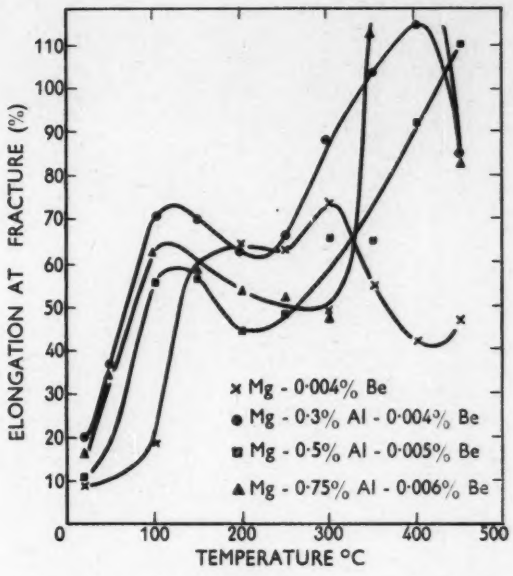


Fig. 2.—Effect of aluminium content on the tensile ductility of Mg-Al-Be alloys.

Table 4 [3]
ELASTIC MO

	20	50	100
Modulus of rigidity, n (lb/in² × 10⁻⁶)	2·37	2·33	2·26
Young's modulus*, E (lb/in² × 10⁻⁶)	6·35	6·25	6·06

n determined by torsional oscillation method : frequency of oscillation 2 to 3 c/s.
* E calculated from n assuming Poisson's ratio 0·33.

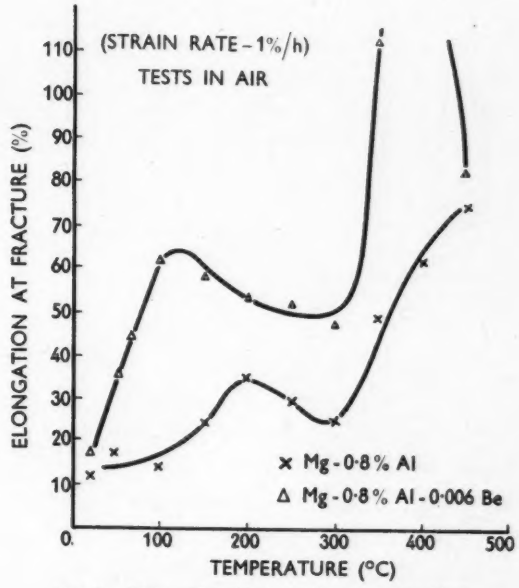


Fig. 3.—Effect of beryllium on the tensile ductility.

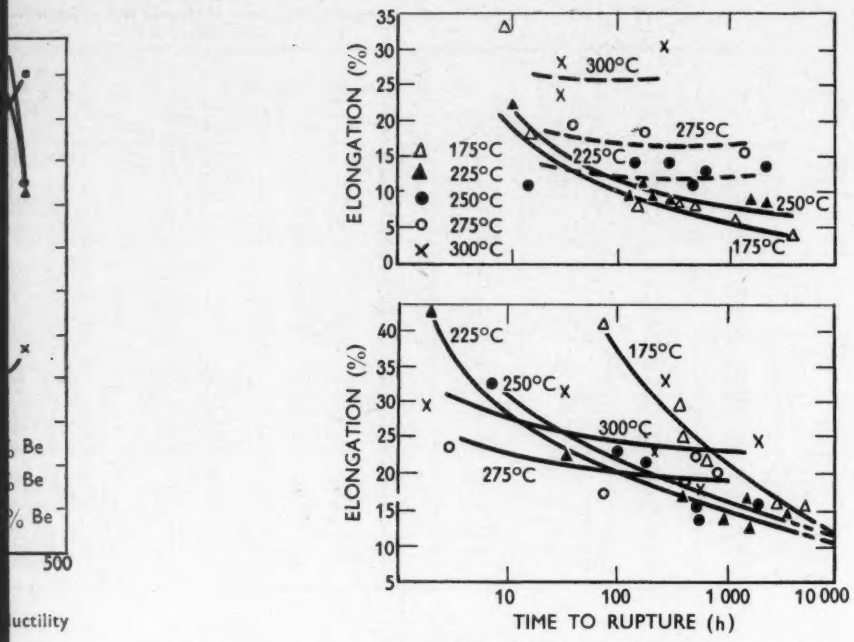


Fig. 4.—Effect of time to rupture on the creep ductility.
Grain size (top) 0·0015 in (bottom) 0·007 in.

Table 4 [3]
ELASTIC MODULI

	Temperature (°C)										
	20	50	100	150	200	250	300	350	400	450	500
..	2·37	2·33	2·26	2·19	2·11	2·02	1·92	1·82	1·71	1·60	1·48
..	6·35	6·25	6·06	5·84	5·62	5·37	5·12	4·85	4·55	4·23	3·99

ncy of oscillation 2 to 3 c/s.

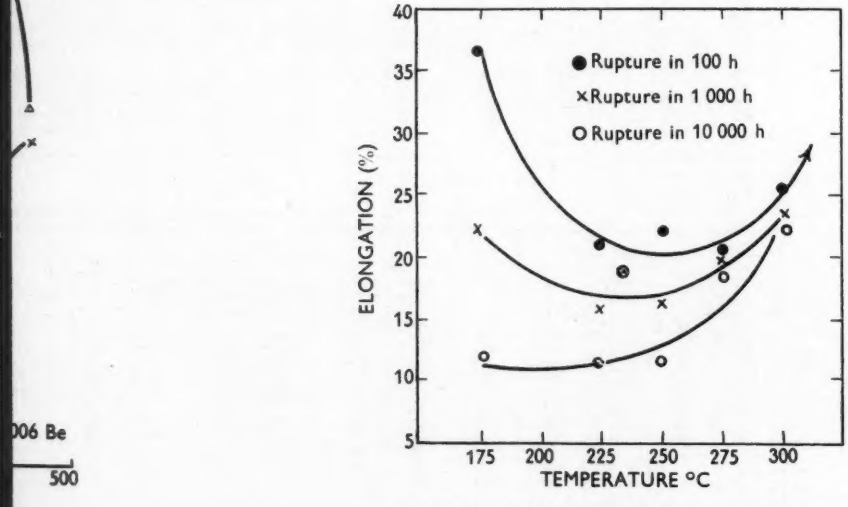


Fig. 5.—Effect of temperature on the creep ductility.
Grain size 0·007 in.

U.T.S. of M

Temp. (°C)	1 075%/h
R.T.	9·6
50	8·8
100	—
150	6·9
200	4·5
250	3·14
300	2·36
350	1·61
400	1·32
450	0·814
500	0·558
550	—

The Effect of grain size o

Temp. (°C)	1–5 grains/$\frac{1}{8}$ in	
	U.T.S. ton/in²	Elongn. %
150	4·82	39·5
	4·83	36·8
180	3·94	34·8
	3·82	39·6
200	3·32	39
	3·55	44·6
250	2·2	46·4
	2·37	50·7

Effect of Aluminiu

Temp. (°C)	Mg-·004%
R.T.	8·2
50	—
100	3·9
150	2·0
200	1·34
250	0·74
300	0·54
350	0·27
400	0·18
450	0·15

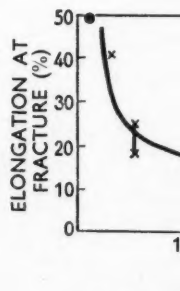


Fig. 6.—Effect

Table 5
U.T.S. of Magnox A12 for various strain rates

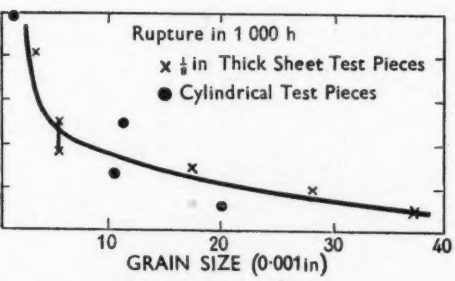
	U.T.S. (ton/in²)			
	1 075%/h[2]	112%/h[2]	18%/h[2]	1%/h[2]
	9·6	9·5	8·9	11·2
	8·8	9·5	—	9·4
	—	8·2	6·7	5·8
	6·9	5·7	4·6	3·5
	4·5	3·65	3·0	2·38
	3·14	2·62	2·10	1·58
	2·36	1·83	1·44	0·94
	1·61	1·32	0·80	0·51
	1·32	0·73	0·58	0·28
	0·814	0·27	—	0·16
	0·558	0·245	—	—
	—	—	0·08	—

Table 6 [2]
of grain size on the tensile properties of Magnox A12. Strain rate—18%/h

-5 grains/$\frac{1}{8}$ in		10–20 grains/$\frac{1}{8}$ in		40–80 grains/$\frac{1}{8}$ in		>100 grains/$\frac{1}{8}$ in	
T.S. /in²	Elongn. %	U.T.S. ton/in²	Elongn. %	U.T.S. ton/in²	Elongn. %	U.T.S. ton/in²	Elongn. %
82	39·5	5·08	67·7	5·29	81	6·2	86
83	36·8	5·01	71·5	4·9	78·8	5·9	66·4
94	34·8	4·06	69·2	4·09	67·6	4·75	60·9
82	39·6	3·95	58·3	4·13	78·6	4·74	69·7
32	39	3·21	54·3	3·65	86·2	3·86	74·5
55	44·6	3·6	58	3·9	81·5	4·13	72
2	46·4	2·53	59·4	2·18	73·7	2·3	86·8
37	50·7	2·48	58·4	2·43	78·2	2·18	67·4

Table 7
: of Aluminium Content on U.T.S. of A12-type Alloys [2]
Strain rate—1%/h

C)	Mg–·004% Be	Mg–·3% Al –·004% Be	Mg–·5% Al –·005% Be	Mg–·75% Al –·006% Be
	8·2	10·8	10·6	11·2
	—	8·9	—	9·4
	3·9	5·2	5·2	5·8
	2·0	3·1	3·4	3·5
	1·34	1·60	2·10	2·38
	0·74	1·14	1·40	1·58
	0·54	0·69	0·73	0·94
	0·27	0·44	0·42	0·51
	0·18	0·23	0·27	0·28
	0·15	0·20	0·13	0·16



ig. 6.—Effect of grain size on the creep ductility.
At temperature of 200°C.

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DATA SHEE

No. 16 Magnox

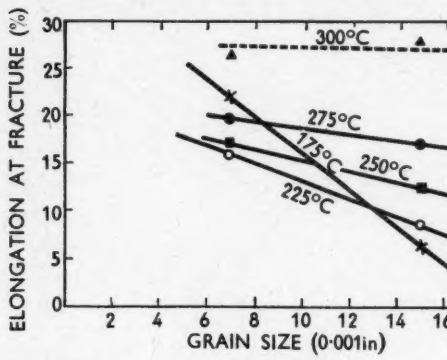

Fig. 7. Effect of grain size on the creep ductility at
temperatures.
Time scale 1 000 h.

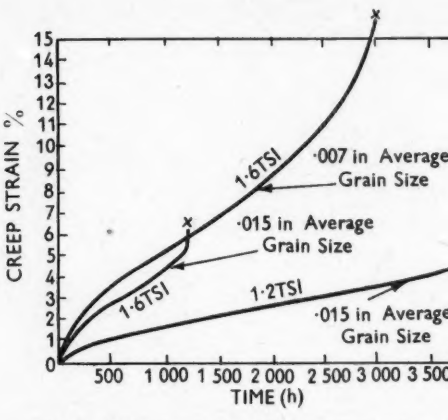

Fig. 8. Creep curves for fine and coarse grained A
At temperature of 175°C.

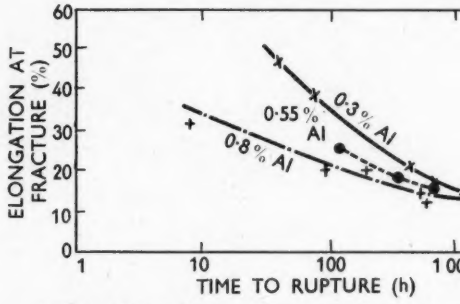

Fig. 9. Effect of aluminium content on creep ducti
At temperature of 250°C.

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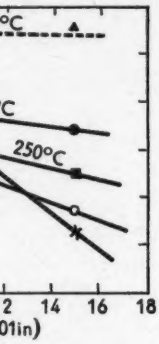
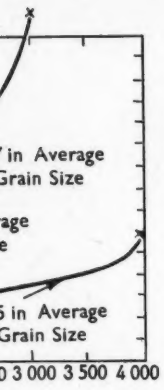


ductility at various



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C.

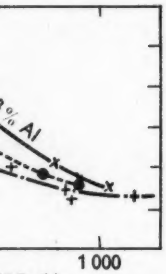

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TABLE 8(a)
Stress Rupture Properties of Magnox A12 rolled sheet
Grain size—0·016 in

Temp. (°C)	Stress ton/in²	Time (h) for specified creep strain %						Min. secondary creep rate in/in h
		0·5	1·0	2·0	5·0	10·0	20·0	
175	3·0	0·1	0·2	0·4	1·4	3·4	6·75	2·37×10
175	2·4	0·1	0·25	0·75	3·5			
175	2·4	0·25	1·5	7	52·5			3·79×10
175	2·0	3	9	36	228			1·29×10
175	1·8	2	13	66	378			9·17×10
175	1·6	12	50	235	1 145			2·75×10
175	1·2	80	340	1 300	3 930			9·33×10
225	2·0	0·1	0·2	0·5	1·9	5·2		1·52×10
225	1·8	1	8	104	150			6·46×10
225	1·4	1	5·5	36	141			2·62×10
225	1·2	2	14	54	249			1·45×10
225	1·0	15	80	375	1 260			3·03×10
225	0·8	110	355	850	2 015			1·52×10
250	1·5	0·25	0·5	1·75				4·8×10⁻³
250	1·2	2	5	14	57	128		6·75×10
250	1·1	12	31	80	183			1·88×10
250	0·92	4	16	54	238			1·32×10
250	0·84	6	25	80	264	466		1·51×10
250	0·84	18	46	116	320	565		1·42×10
250	0·75	75	185	435	1 170	1 980		3·93×10
275	1·2	0·1	0·5	2	9	23		3·59×10
275	0·9	1·5	6	17	54	112		8·1×10⁻⁴
275	0·55	35	85	185	502	1 000		9·53×10
300	1·0	0·25	0·75	2	7	15		5·83×10
300	1·0	0·25	0·5	1·5	5·75	14		5·93×10
300	0·6	3·5	9	19·5	54			8·55×10

TABLE 8(b)
Grain size—0·008 in

Temp. (°C)	Stress ton/in²	Time (h) for specified creep strain %						Min. secondary creep rate in/in h
		0·5	1·0	2·0	5·0	10·0	20·0	
175	2·8	0·125	0·2	1	6	22		2·98×10
175	2·6		0·5		17·5	76	302	2·73×10
175	2·2	0·5	1·5	5	50	174	379	3·64×10
175	2·0	1	3	16	110	34		2·03×10
175	1·6	4	21	135	900	2 220		3·3×10⁻⁵
175	1·8	15	72	280	1 530	3 860		1·9×10⁻⁵
225	2·72		0·08	0·16	0·33	0·60		—
225	1·8	0·1	0·2		6·8	19·3		3·99×10
225	1·4	3	7	26	103	236		3·35×10
225	1·2	8	26		348	722		1·10×10
225	1·0	17	50		566	1 060		6·90×10
225	0·9	20	80	260	850	1 540		5·13×10
250	1·85	0·06	0·125	0·25	1·125	2·75	5·875	3·02×10
250	1·4	0·5	1·5	6·5	29	60		1·2×10⁻³
250	1·1	0·5	3	11	51	121	193	7·18×10
250	0·85	7	24	71	213	405		2·12×10
250	0·8	13	40	99	264	451		1·7×10⁻⁴
250	0·6	210	315	490	945	1 635		5·25×10
275	1·8							
275	1·4	0·06	0·1	0·2	0·75	1·875	3	4·46×10
275	1·0	0·5	1·5	6	23·5	50·5		1·77×10
275	0·7	6	19	45	126	243		3·61×10
275	0·6	15	40	84	205	380		2·11×10
275	0·6	18	50	114	300			1·57×10
300	1·6	0·5	1	1·5	11	28		2·96×10
300	1·0	0·25	0·5	1·5	5·25	14·5	26·5	4·5×10⁻³
300	0·8	13	36	81	136	176	227	2·37×10
300	0·52	7	17	37	87	160		6·15×10
300	0·50	20	48	130	396	892		1·08×10

TABLE 9
Intergranular Cavity Distributions due to slow straining in Magnox

Temp. (°C)	Grain size 0·001 in	Strain rate in/in h ×10³	Time (h)	Strain %	Cavities/cm²					Level of Cavitation p*	
					<10μ	10–20μ	20–40μ	40–80μ	>80μ		80–12
175	15	2·265	675	1·53	381	100	41			46	4
175	14	2·265	1 013	2·29	533	155	78	19	12	97	8
175	13	2·265	1 519	3·44	630	206	89	65	19	147	25
225	12	2·265	675	1·53	534	119	53	11	4	71	4
225	12	2·265	1 013	2·29	597	119	46	3	6	69	14
225	12	2·265	1 519	3·44	408	153	108	63	18	132	25
175	6·5	2·265	675	1·53	37	3				2·3	
175	6	2·265	1 013	2·29	80	30	3			9·4	
175	4·8	2·265	1 519	3·44	226	86	40	11		43	
225	5·3	2·265	675	1·53	135	30	6			14·1	
225	6	2·265	1 013	2·29	56	37	16	11		19·8	
225	6·2	2·265	1 519	3·44	93	51	51	18	12	50·6	

$*p = \frac{\Sigma nx}{100}$

† " Stringer " defined as " row of cavities where the distance between adjacent cavities does not exceed twice the
n = number of cavities in each size group.
x = mean size of cavity in each group (in microns).

TABLE 8(a)

Properties of Magnox A12 rolled sheet [3]

Grain size—0·016 in

creep strain %			Min. secondary creep rate in/in h	Total creep strain %	Time to rupture (h)	Strain % to end of secondary creep	Time to end of secondary creep (h)
5·0	10·0	20·0					
1·4	3·4	6·75	$2·37\times10^{-3}$	32·7	8·75	12·6	4·5
3·5				17·8	14		
52·5			$3·79\times10^{-4}$	9·8	133	7·6	118
228			$1·29\times10^{-4}$	8·7	374	5·8	293
378			$9·17\times10^{-5}$	8·1	488	5·6	440
145			$2·75\times10^{-5}$	6·3	1 157	3·7	800
930			$9·33\times10^{-6}$	5·9	3 988	3·6	3 000
1·9	5·2		$1·52\times10^{-3}$	21·9	10	11·3	6
150			$6·46\times10^{-5}$	11·6	156	1·8	90
141			$2·62\times10^{-4}$	9·4	206	5·5	160
249			$1·45\times10^{-4}$	8·8	322	4·7	230
260			$3·03\times10^{-5}$	8·6	1 717	3·5	870
015			$1·52\times10^{-5}$	8·0	2 300	2·7	1 180
			$4·8\times10^{-3}$	10·8	15		
57	128		$6·75\times10^{-4}$	13·8	144	9	118
183			$1·88\times10^{-4}$	13·6	275	2	80
238			$1·32\times10^{-4}$	9·2	374	3·8	175
264	466		$1·51\times10^{-4}$	11·5	494	3·5	180
320	565		$1·42\times10^{-4}$	12·4	623	6	380
170	1 980		$3·93\times10^{-5}$	13·8	2 326	4·6	1 100
9	23		$3·59\times10^{-3}$	19·4	38	14	34
54	112		$8·1\times10^{-4}$	17·9	163·5	8	80
502	1 000		$9·53\times10^{-5}$	15·5	1 419	7·9	800
7	15		$5·83\times10^{-3}$	27·8	29·5	9	13·5
5·75	14		$5·93\times10^{-3}$	23·4	30	14	21
54			$8·55\times10^{-4}$	30·6	261	11·5	130

TABLE 8(b)

Grain size—0·008 in

eep strain %			Min. secondary creep rate in/in h	Total creep strain %	Time to rupture (h)	Strain % to end of secondary creep	Time to end of secondary creep (h)
·0	10·0	20·0					
6	22		$2·98\times10^{-3}$	42·7	69	11·3	26
17·5	76	302	$2·73\times10^{-4}$	29·6	384		
50	174	379	$3·64\times10^{-4}$	25·7	422	13·2	260
10	34		$2·03\times10^{-4}$	22·2	780	13·7	525
00	2 220		$3·3\times10^{-5}$	16·4	3 003	8	1 800
30	3 860		$1·9\times10^{-5}$	14·8	5 271	7·8	3 000
0·33	0·60		—	43·0	2		
6·8	19·3		$3·99\times10^{-3}$	23·2	40	12·2	25
03	236		$3·35\times10^{-4}$	18·1	352	7·8	182
48	722		$1·10\times10^{-4}$	14·0	846	7·4	560
66	1 060		$6·90\times10^{-5}$	16–17	1 394	5·8	675
50	1 540		$5·13\times10^{-5}$	13·2	1 714	6·3	1 100
1·125	2·75	5·875	$3·02\times10^{-3}$	32·4	8	13·7	4
29	60		$1·2\times10^{-3}$	22·6	98	6·6	42
51	121	193	$7·18\times10^{-5}$	21·4	196	10·0	120
13	405		$2·12\times10^{-4}$	16·4	525	6·0	260
54	451		$1·7\times10^{-4}$	14·4	542	4·0	220
35	1 635		$5·25\times10^{-5}$	15·8	1 992	5·5	1 040
				23·5	0·17		
0·75	1·875	3	$4·46\times10^{-3}$	23·6	3·17	8·6	1·625
23·5	50·5		$1·77\times10^{-3}$	17·6	77	8·4	44
66	243		$3·61\times10^{-4}$	19	350	5·8	150
35	380		$2·11\times10^{-4}$	23·6	575	6·6	270
0			$1·57\times10^{-4}$	19·8	816		
1	28		$2·96\times10^{-4}$	29·6	1·5		
5·25	14·5	26·5	$4·5\times10^{-3}$	31·0	36		
6	176	227	$2·37\times10^{-4}$	24·2	237	2·5	100
7	168		$6·15\times10^{-4}$	33·4	309	7·7	130
6	892		$1·08\times10^{-4}$	24·6	2 294	18·5	1 640

TABLE 9

butions due to slow straining in Magnox A12 strip [3]

ties/cm³			Level of Cavitation p*	Stringers†/cm²				Longest stringer	
–40μ	40–80μ	>80μ		80–120μ	120–160μ	160–200μ	>200μ	μ	0·001 in
41			46	4		1	1	240	10
78	19	12	97	8	2	3	6	380	14·2
89	65	19	147	25	6	5	4	280	11·6
53	11	4	71	4	2	2	2	250	10
46	3	6	69	14	3	2	2	320	12·8
108	63	18	132	25	11	8	6	382	15·3
			2·3						
3			9·4						
40	11		43	No long stringers developed					
6			14·1						
16	11		19·8						
51	18	12	50·6						

adjacent cavities does not exceed twice the average cavity diameter."

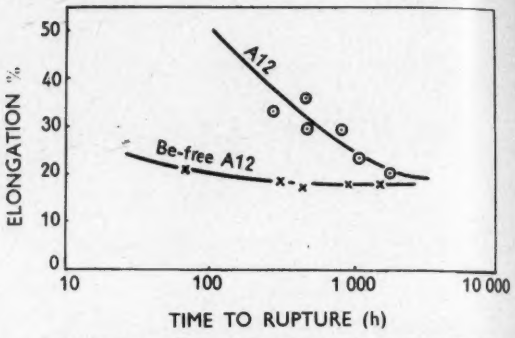

Fig. 10. Effect of beryllium content on creep ductility.
At temperature of 250°C.

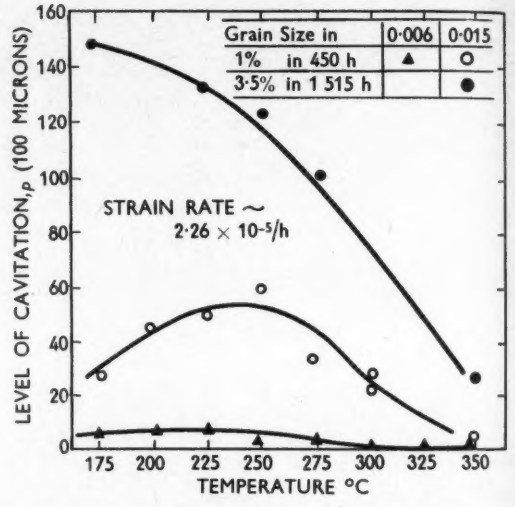

Fig. 11. Effect of temperature on the extent of intergranular cavitation.

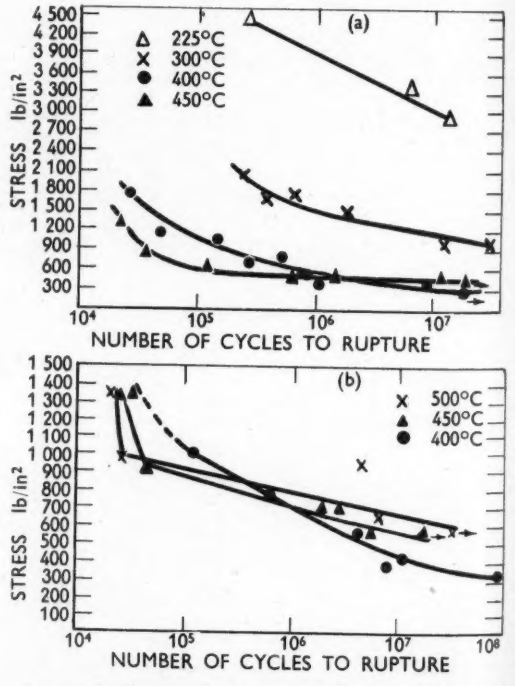

Fig. 12. Effect of temperature on fatigue strength.
Grain size (top) 0·006 in (bottom) 0·00001 in.

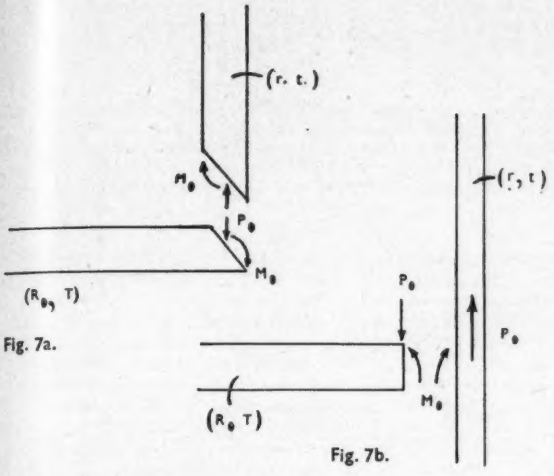

Fig. 7a.

Fig. 7b.

Rotation of the branch at the joint

$$\phi_o^1 = (2\beta_2 M_\theta)/2\beta_2^2 D_2,$$

where $\beta_\theta = n/(R_\theta T)^{1/2}$, $\beta_2 = n/(rt)^{1/2}$

$D_1 = ET^3/4n^4$, $D_2 = Et^3/4n^4$,

$n^4 = 3(1-\nu^2)$,

and R_θ is the appropriate radius of curvature of the strip at θ. Where the branch is considerably smaller than the cylinder, R_θ can be taken as the maximum radius of curvature of the ellipse produced by cutting the cylinder at an angle θ:

$$R_\theta = R \sec^2 \theta.$$

The radial deflection ω_o of the cylinder at the joint is assumed to be independent of θ giving the end thrust per unit length of periphery as

$$P_\theta = 4\beta_\theta^3 D_1 \omega_o(1+q_\theta)/(2+q_\theta),$$

where $q_\theta = \beta_2 D_2/\beta_\theta D_1 = (Rt^5/rT^5)^{1/2} \sec\theta = q \sec\theta$.

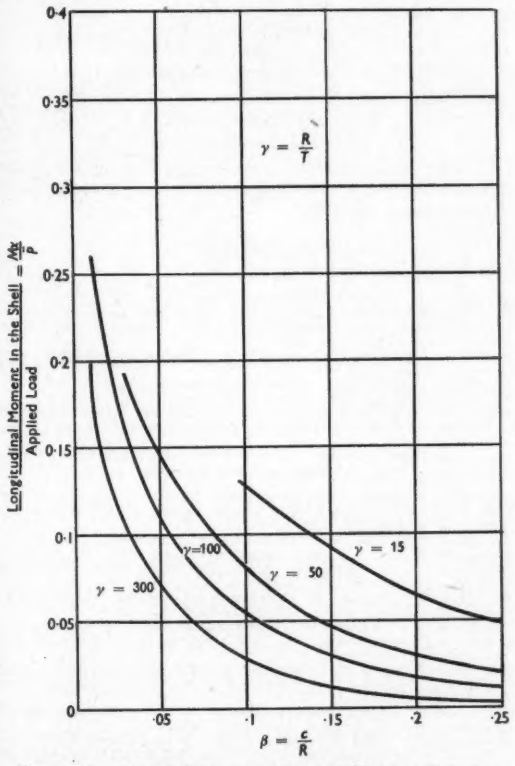

Fig. 8.—Longitudinal moment in a cylindrical shell due to a radial compressive load.

Integrating P_θ around the opening and equating to the applied end thrust $\bar{P}$, the maximum value of P_θ is found to occur at $\theta = 0$.

$P_{max} = \bar{P}m_1/2r$, where $m_1 = \frac{1}{4}$ for a large range of q.

This gives rise to the following stress values:

$$\sigma_{\theta\,max} = -\frac{E\omega_o}{R} = -\frac{3n(RT)^{1/2}\bar{P}}{8rT^2}\left(\frac{2+q}{1+q}\right),$$

$$\sigma_{r\,max} = \pm\frac{6M_\theta}{T^2} = \pm\frac{9(RT)^{1/2}\bar{P}}{8nrT^2}\left(\frac{q}{1+q}\right),$$

$$\sigma_{H\,max} = -\frac{E\omega_o^1}{r} = +\frac{3n(RT)^{1/2}\bar{P}}{8rt^2}\left(\frac{q}{1+q}\right).$$

For through branches, the initial relations for the shell will be as before.

For the branch[12] $\phi_o^1 = M_\theta/4\beta_2 D_2$, giving

$$P_\theta = 2\beta_\theta^3 D_1 \omega_o(1+4q_\theta)/(1+2q_\theta).$$

As before, from the equilibrium of the branch tube under a thrust $\bar{P}$, P_θ is found to be a maximum at $\theta = 0$.

$P_{max} = m_2\bar{P}/4r$ where $m_2 = 3/2$ for a large range of q.

The stress values are then

$$\sigma_{\theta\,max} = -\frac{3n(RT)^{1/2}\bar{P}}{4rT^2}\left(\frac{1+2q}{1+4q}\right),$$

$$\sigma_{r\,max} = \pm\frac{9(RT)^{1/2}\bar{P}}{2nrT^2}\left(\frac{q}{1+4q}\right).$$

M_θ produces no deflection of the branch at its junction with the shell, hence σ_H must be zero.

The stress concentration factors j_3, j_3^1 and j_3^{11} are obtained by dividing the appropriate stresses by $\sigma_1 = pR/T$.

For a branch opening in a spherical shell there is no change in radius of curvature of the shell when sections are taken through the branch axis. The solution is therefore simpler and the following stresses occur.

For flush branches:

$$\sigma_\theta = -\frac{n(RT)^{1/2}\bar{P}}{2\pi rT^2}\left(\frac{2+q}{1+q}\right),$$

$$\sigma_r = \pm\frac{3(RT)^{1/2}\bar{P}}{2\pi nrT^2}\left(\frac{q}{1+q}\right),$$

$$\sigma_H = +\frac{n(RT)^{1/2}\bar{P}}{2\pi rt^2}\left(\frac{q}{1+q}\right).$$

For through branches:

$$\sigma_\theta = -\frac{n(RT)^{1/2}\bar{P}}{\pi rT^2}\left(\frac{1+2q}{1+4q}\right),$$

$$\sigma_r = \pm\frac{3(RT)^{1/2}\bar{P}}{\pi nrT^2}\left(\frac{2q}{1+4q}\right),$$

$$\sigma_H = 0.$$

The stress concentration factors j_3, j_3^1 and j_3^{11} are obtained by dividing the appropriate stresses by $\sigma_1 = pR/2T$.

This method gives reliable results where the diameter to thickness ratio of the branch is greater than 10, and also where the branch diameter does not approach too closely the shell diameter.

Local Loading Method

Where the diameter to thickness ratio is small, the arrangement becomes closer to that of a solid circular bar welded to the shell and subjected to an end thrust. In calculating the stresses in the

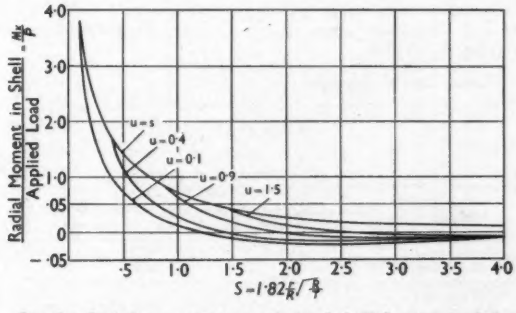

Fig. 9.—Radial moments in a spherical shell due to a radial compressive load.

shell for such a case, the end thrust is assumed applied uniformly over an area of unpierced shell equal to that covered by the branch. Bijlaard has developed equations which enable stresses in the shell under this loading condition to be evaluated for both cylindrical and spherical shells. His results are given in the form of graphs[13, 14, 15, 16, 17].

In the case of the cylinder the local load has been taken to extend over a small rectangular area. Its distribution has been put in double Fourier Series form and it is assumed to be well away from the ends of the cylinder which are taken to be simply supported.

It has been found accurate enough to consider the loads, which are really applied over circular areas of diameter d, to be applied over square areas of side $2c = d$. The ratios $\beta = c/R$ and $\gamma = R/T$ are calculated and the membrane forces, N_x and N_ϕ, and the bending moments, M_x and M_ϕ, in the longitudinal and circumferential directions at the edge of the insert are obtained by interpolation from the graphs of which Fig. 8 is representative. These graphs were derived from calculations for a cylinder whose ratio of length to mean radius was eight. Correction factors, which may be applied to the moments and forces to allow for different values of this ratio, do not exceed 1·1 even for long, thin cylinders.

The stresses are obtained by the equation

$$\sigma = N/T \pm 6M/T^2.$$

As the sphere is a symmetrical case of loading, an exact solution is available. Even so, the solution is best determined by a computer in terms of the non-dimensional parameters u and s, and shown in graphical form. Fig. 9 is representative of the graphs obtained by Bijlaard.

The membrane forces and bending moments in the radial and tangential directions at the edge of the circular insert of radius r_o (Fig. 10) are determined from the top curve $u = s$, where

$$u = 1{\cdot}82\, r_o(R/T)^{1/2}/R.$$

For forces and moments at points in the shell at radial distance r from the axis of the insert, the term s is calculated, and the other curves are used to interpolate the value at s for the appropriate u of the sphere and branch considered

$$s = 1{\cdot}82\, r(R/T)^{1/2}/R$$

and as before

$$\sigma = N/T \pm 6M/T^2.$$

If this method of calculation is also applied to nozzles which have larger diameter to thickness ratios the results give good agreement with those derived from the previous method, although quite different assumptions are used in the two calculations.

Comparison of Methods

The circumferential and radial stresses produced in a 4 in thick cylindrical shell of 50 ft diameter by a compressive load of 10 ton acting on a branch tube of 54 in bore with 2¼ in thick walls have been calculated by the different methods and are shown in Table 1.

For a spherical shell of mean radius 300 in with 3 in thick walls, the stresses around a branch tube 2 in thick with an outside diameter of 38 in which carries a compressive load of 10 ton are given in Table 2.

In the local loading analyses for both cylinder and sphere, the flexibility of the pipe itself is not considered. There are therefore no equations for stresses in the branch itself.

For the sphere only, a further analysis by Bijlaard[18] has been carried out allowing for the flexibility of a branch. However, it only considers a flush branch and the results are shown by means of a large number of graphs from which results are interpolated for the required values of u, s, $\varrho = T/t$ and $\gamma = r/t$.

Since this article was prepared a paper has been published by Rose and Thompson which covers the case of a through branch in a spherical shell[19].

End Thrust Due to Pressure (j_3, j_3^1, j_3^{11})

When the end thrust is due to internal pressure only

$$\bar{P} = \pi r^2 p.$$

Table 1

Method	Circumferential Stress ton/in²	Radial Stress ton/in²
Elastic foundation—Through branch	−0·462	±0·512
Elastic foundation—Flush branch	−0·581	±0·295
Local loading ..	±0·331−0·84 = −0·426 or +0·236	±0·215−0·084 = −0·299 or +0·131

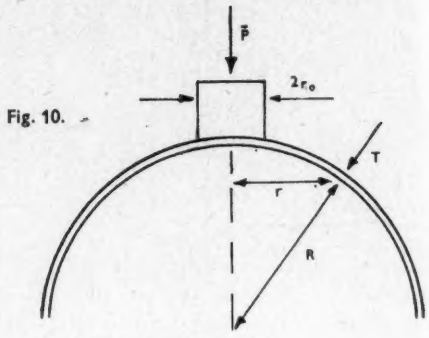

Fig. 10.

Table 2

Method	Circumferential Stress ton/in²	Radial Stress ton/in²
Elastic foundation—Through branch	−0·434	±0·589
Elastic foundation—Flush branch	−0·531	±0·4107
Local loading ..	±0·125−0·38 = −0·163 or +0·087	±0·437−0·124 = −0·561 or +0·313

The stress concentration factors derived by the Beam on Elastic Foundation method may be put in a more convenient form.

For the cylinder:

for a flush branch

$$j_3 = -3\pi nrT(RT)^{1/2}q/(1+q)\,8Rt^2,$$
$$j_3^1 = +3\pi nr(2+q)/(1+q)\,8(RT)^{1/2},$$
$$j_3^{11} = \pm\, 9\pi rq/(1+q)\,8n(RT)^{1/2};$$

for a through branch,

$$j_3^1 = +3\pi nr(1+2q)/(1+4q)\,4(RT)^{1/2},$$
$$j_3^{11} = \pm\, 9\pi rq/(1+4q)\,2n(RT)^{1/2}.$$

For the sphere:

for a flush branch,

$$j_3 = -nrT(RT)^{1/2}q/(1+q)\,Rt^2,$$
$$j_3^1 = +nr(2+q)/(1+q)(RT)^{1/2},$$
$$j_3^{11} = \pm\, 3rq/(1+q)\,n(RT)^{1/2}.$$

For a through branch:

$$j_3^1 = +2nr(1+2q)/(1+4q)(RT)^{1/2},$$
$$j_3^{11} = \pm 12r\,q/(1+4q)\,n(RT)^{1/2}.$$

If the local loading method is used, exactly the same procedure is adopted with the end thrust computed for the particular dimensions and pressure required.

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Ceramics—Thermal Stress Resistance

Ceramics used in a reactor may be subjected to transient thermal stresses or stresses due to thermal shock caused by a temperature gradient which changes with time, alternatively there may be steady state stresses associated with a temperature gradient constant with time. This article concludes the series on ceramics and ends with a brief summary of nuclear applications.

by J. L. EVANS

THE removal of heat from nuclear reactors necessarily imposes temperature gradients on the reactor materials. These temperature gradients give rise to stresses due to unequal expansions and, if sufficiently large, can result in failure of the component. With metals the high thermal stresses can normally be relieved by plastic flow, but ceramics lacking ductility fail when the elastic limit is reached.

It is convenient to differentiate between two types of stresses: transient thermal stresses or stresses due to thermal shock which are associated with a temperature gradient which changes with time; steady state stresses associated with a temperature gradient which is constant with time. In the theoretical treatment of the subject it is assumed that the material under study is elastic, homogeneous and isotropic, that fracture occurs when the stress reaches a critical value, and that the mechanical and physical properties are essentially constant over the temperature range considered.

A quantitative measure of the thermal stress resistance is the maximum temperature difference necessary to cause a specified fracture or weakening of a specific shape under defined thermal conditions. The most satisfactory parameter for purposes of calculation is that temperature difference necessary to cause stresses equal to the fracture stress of the ceramic under consideration. The stress value taken is normally that in bending where failure is by tensile forces. This test is chosen as failure under thermal stresses is due generally to tensile forces, the tensile strengths of ceramics being 4–8 times lower than their compressive strengths.

Transient Thermal Stresses

The two cases of interest are, first, where the heat transfer coefficient, h is infinite and, second, where it is finite. If on quenching, h is infinite so that the surface of the material initially at t_o is immediately changed to t_1 whilst the average temperature, t_a, of the material remains at t_o, the stress σ_s at the surface of a "long" cylinder given by:

$$\sigma_s = E\alpha(t_o - t_s)/(1-\mu) \tag{1}$$

becomes,

$$\sigma_{max} = E\alpha(t_o - t_1)/(1-\mu) \tag{2}$$

where E, α and μ are Young's modulus, coefficient of linear expansion and Poisson's ratio respectively.

The temperature difference to cause fracture is thus:

$$t_o - t_1 = S_t(1-\mu)/E\alpha \tag{3}$$

where S_t is the modulus of rupture.

For shapes other than cylinders geometrical constants are required and if we define a property's constant $R = S_t(1-\mu)/E\alpha$, and a shape factor S_1 giving the stress dependence on the shape of the specimen, then in general

$$t_o - t_1 = R\,S_1.$$

For most ceramics μ varies from 0·2 to 0·35 and consequently the term $(1-\mu)$ varies from 0·65 to 0·8 and can be considered essentially constant. It is convenient to include the $(1-\mu)$ term in S and to define $R = S_t/E\alpha$.

The second case where the heat transfer coefficient h is finite but constant has received most attention in the literature as it is the condition that often approximates to that found in practice. The highest value of the tensile stresses still occurs at the surface but not immediately after quenching; a finite time is now required for the establishment of the maximum gradient and hence the maximum stress. For a given body the maximum stress developed decreases and the time to reach this maximum stress increases as h decreases. In addition to the heat transfer coefficient the time to reach maximum stress is also influenced by the cylinder radius r_m, and the thermal conductivity k.

The ratio of the maximum surface stress reached, σ', to that of its maximum value when $h = \infty$, σ_{max}, is called the maximum non-dimensionless stress σ^*_{max}.

$$\sigma^*_{max} = \frac{\sigma'}{\sigma_{max}} = \frac{\sigma'(1-\mu)}{E\alpha(t_o - t_1)}. \tag{4}$$

With gas convection and radiation cooling where β $(= r_m h/k)$ is low, several approximate relationships between σ^*_{max} and β have been suggested[2, 3, 4]. That according to Bradshaw[2]

$1/\sigma^*_{max} = 4/\beta$ holds for values of $\beta < 2$.

Equation 4 then becomes

$$\frac{\beta}{4} = \frac{\sigma'(1-\mu)}{E\alpha(t_o - t_1)} \tag{5}$$

and the temperature difference to cause failure

$$(t_o - t_1) = \frac{S_t(1-\mu)}{E\alpha}\,\frac{4k}{r_m h}. \tag{6}$$

(At higher values of β the calculation of $(t_o - t_1)$ values is best achieved graphically.) Fig. 1 gives a plot of σ^*_{max} against β for the case of a thin disc insulated on its faces so that in quenching the heat flow is radial. In this case the term $(1-\mu)$ does not appear in the equation for σ^*_{max}.

For other shapes similar equations are obtainable and these can be expressed generally as

$$(t_o - t_1) = R^1 S_2/h \tag{7}$$

where $R^1 = kR = S_t k/E\alpha$ is the second thermal shock resistance factor and S_2 is a shape factor for the sample under consideration. From the foregoing it is clear that the thermal shock resistance of a material will be determined by $R = S_t/E\alpha$ at high values of h and by $k\,S_t/E\alpha$ at low values of h as the value of μ for most ceramics does not vary widely.

NOMENCLATURE

α	Coefficient of linear expansion	/°C
β	Biot's modulus–$r_m h/k$	Dimensionless
E	Young's modulus	lb/in²
h	Heat transfer coefficient	cal/cm²s°C
k	Thermal conductivity	cal/cm s°C
R	First thermal stress parameter $S_t/E\alpha$	°C
R^1	Second thermal stress parameter $k\,S_t/E\alpha$	cal/cm s
Q	Heat flux	cal/cm s or kW/ft
r_1	Inside diameter of tube	cm
r_2	Outside diameter of tube	cm
r_m	Radius of solid cylinder	cm
$S_{(1\text{-}4)}$	Shape factors	
S_t	Modulus of rupture	lb/in²
σ_{max}	Maximum surface stress when $h=\infty$	lb/in²
σ^*_{max}	Ratio of maximum surface stress under given conditions to that when $h=\infty$	Dimensionless
σ'	Maximum surface stress $h \neq \infty$	lb/in²
t_a	Average temperature of material $= \frac{2}{r_m^2}\int_0^{r_m} T_r dr$	°C
T_r	Temperature of cylinder rcm from centre	°C
t_s	Surface temperature	°C
t_o	Initial body temperature	°C
t_1	Temperature of surroundings	°C
Δt	Temperature difference across tube wall	°C
Δt_f	Temperature difference across tube wall which causes failure	°C
μ	Poisson's ratio	Dimensionless

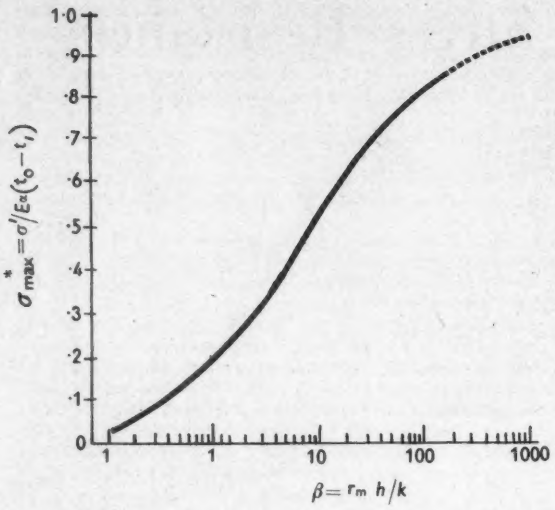

Fig. 1.—Maximum dimensionless stress versus dimensionless heat transfer (after Manson[4]).

Steady State Thermal Stresses

The tensile stress in the outer surface of a long hollow cylinder with an internal heat source giving a uniform temperature drop Δt is

$$\sigma_s = \frac{E\alpha\Delta t}{1-\mu}\left(1-\frac{2r_1^2}{r_2^2-r_1^2}\log_e\frac{r_2}{r_1}\right)\Big/2\log_e\frac{r_2}{r_1} \qquad (8)$$

where r_1 and r_2 are the inner and outer radii of the tube. The temperature difference to cause failure is

$$\Delta t_f = \frac{S_t(1-\mu)}{E\alpha}2\log_e\frac{r_2}{r_1}\Big/\left(1-\frac{2r_1^2}{r_2^2-r_1^2}\log_e\frac{r_2}{r_1}\right) = RS_3 \qquad (9)$$

where $R = S_t/E\alpha$ and S_3 is a general shape factor term which includes the $(1-\mu)$ term.

For radial heat flow $q = 2\pi k\Delta_t/\log_e(r_2/r_1)$, and

$$q_{max} \doteq 2\pi kRS/\log_e(r_2/r_1) = R^1 S_4 \qquad (10)$$

where $R^1 = kR = S_t\,k/E\alpha$ and S_4 is the shape factor.

In general the maximum steady state heat flux tne material can withstand is of greatest interest and consequently the factor R^1 is of greater importance.

Similar formulae are available for the steady state case where self heating occurs which is applicable to ceramics which contain fissile material. For example, the tangential stress at the surface of a long solid cylinder radius a with a heat generation H per unit volume[5] is

$$\sigma = \frac{E\alpha}{(1-\mu)}\frac{Ha^2}{8k}. \qquad (11)$$

The heat generated per unit length $q = \pi a^2 H$,

$$q_{max} = 8\pi(1-\mu)k\ S_t/E\alpha = R^1 S_5 \qquad (12)$$

and

$$\Delta t_f = 2\ S_t(1-\mu)/E\alpha = R\ S_6. \qquad (13)$$

Factors Affecting Thermal Stress Resistance

The foregoing discussion has given two thermal stress resistance parameters. However, only the simplest of cases have been considered and Kingery[1] indicates that different conditions, i.e., a stress associated with a constant rate of heating and cooling or cooling by radiation which gives a variable heat transfer coefficient, will introduce other factors which will necessitate additional thermal stress parameters. Consequently it is impossible to give a single property factor for the resistance of a material to thermal stresses.

Increasing the size of the component increases the parameter β and if the size is sufficiently large the conditions approach those expressed in equations 2 and 3 and the thermal stress resistance is essentially independent of h and k. For moderate values of β equation 6 indicates that $(t_o - t_1)$ is proportional to $1/\beta$ and consequently the thermal stress resistance is inversely proportional to the specimen dimensions. This has been verified experimentally by Manson[6] (Fig. 2).

For a thin walled tube subjected to a steady state temperature gradient, doubling the wall thickness at any given heat flux approximately doubles the thermal stress. On the other hand, doubling the wall thickness at a constant value of Δt, gives no increase in stress but the heat flux is, of course, halved.

The theory assumes that some dimensions are infinite. The effect of edges due to specimens being non-infinite can be assessed from elastic theory[7] and it has been shown that for cylinders, departures from an infinite length are not important until the length is less than twice the inside diameter.

The second thermal stress resistance factor R^1 indicates that the thermal stress resistance under a given heat flux and the thermal shock resistance at moderate values of β are influenced by the conductivity. The thermal stress resistance of ceramic materials falls with rising temperatures and this is due to the rapid fall in conductivity with temperature[8], while the property values which make up R^1 are generally fairly constant up to 1 000°C. Arthur[9] indicates that the conductivity values are influenced by both impurities and porosity and consequently for the highest conductivity and thermal stress resistance, high purity and low porosity are necessary. Fig. 3 shows the effect of temperature on S_t, α, E, k and on R and R^1 for alumina.

The effect of porosity can be predicted from the effect of porosity on the parameters which make up R and R^1. Arthur[8] has given graphs indicating these effects, and Fig. 5 shows curves of R and R^1 against porosity. The rapid fall in R is due to the greater effect of porosity on the strength than on Young's modulus, α the coefficient of linear expansion being unaffected. R^1 falls at an even greater rate due to the fall in conductivity with porosity.

Of all the properties which influence the thermal stress resistance, the thermal expansion changes least with temperature. This only applies to homogeneous bodies which exhibit no magnetic or polymorphic transformations. The expansion coefficients vary from such high values as 14×10^{-6}/°C for MgO to $0{\cdot}55\times10^{-6}$/°C for fused silica[9]. The excellent thermal shock resistance of fused silica is well known and its low thermal expansion accounts for this property.

While the assumption that failure occurs as soon as the elastic limit is reached holds at lower temperature where ceramics behave as brittle materials, at higher temperatures where plastic flow can occur, the stress distribution is not that assumed and higher stresses can be accommodated without failure. Similarly plastic

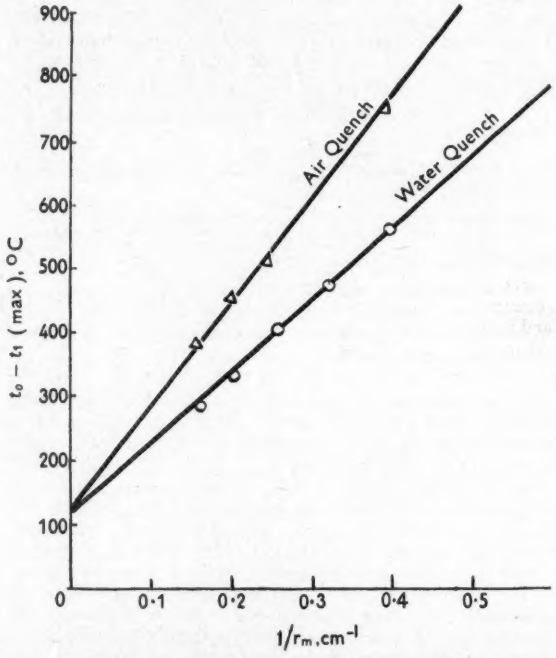

Fig. 2.—Experimental variation of $t_o - t_1$ (max) with cylinder radius for Steatite cylinders quenched into air and water (after Manson[6]).

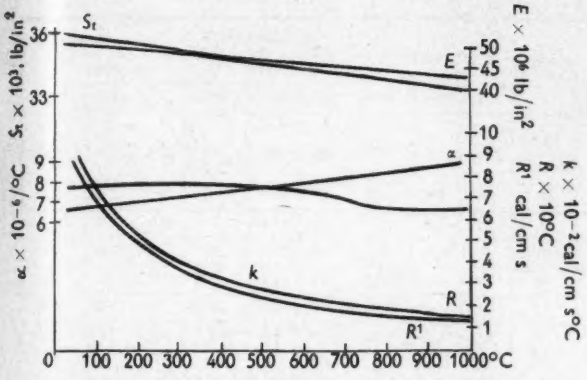

Fig. 3.—Variation with temperature of S_t, E, α, k and thermal stress resistance factors for dense alumina.

flow occurs on bend testing and the value of the strain to failure rather than σ/E over the elastic range is best substituted in the formulae for R and R^1. The increasing plasticity at elevated temperatures increases the thermal stress resistance and this has been verified by Schwartz[10] who showed that the thermal stress resistance of alumina increased appreciably above 1 200°C.

The parameter μ is relatively constant for ceramics (0·2–0·35) and changes little with temperature although at higher temperatures μ increases.

From the equations for R and R^1 it would appear that a high strength value is desirable in any thermal stress resistant ceramic. However, in general, a high strength is associated with a high value of Young's modulus and consequently the parameter S_t/E may be little affected.

As indicated, the strength values taken are those in bending due to the similarity to the stress distribution under temperature gradients. In addition the ease of testing in bending makes this method more attractive than tensile methods where misalignment and stress concentration at the grips makes the determination of accurate results difficult.

The effect of the conductivity on the thermal shock resistance of any material depends on the value of h and r_m. As k varies widely with temperature and between materials it is not surprising in some cases that the order of merit of the resistance of materials to thermal stresses changes as h changes. Thus at low values of h, BeO because of its superior conductivity has better thermal shock properties than Al_2O_3, but at higher values of h this is no longer so. Fig. 4 shows the variation of $(t_o - t_1)$ with the heat transfer parameter $r_m h$ taken from Kingery[1].

Determination of Thermal Shock Parameters

For most ceramics, the most convenient way of expressing the thermal stress resistance is in terms of R and R^1. Their determination from experimental values of the various parameters entails a considerable effort and requires many specimens but has the advantage of giving detailed information about a given material over a wide temperature range. However, as S_t, E and α change little with temperature up to 1 000°C, the determination of this factor at one temperature together with the determination of k over a wide temperature range is sometimes satisfactory.

The direct experimental determination of R is most easily achieved in a steady state test with a suitably shaped body, usually a tube. The accurate measurement of h is difficult and is consequently a disadvantage in measuring R and R^1 by thermal shock methods. This can be avoided, however, by using sufficiently large samples such that $\beta = r_m h/k$ is very large and equation 3 for R is applicable. The separate determination of k gives R^1.

The correlation between theory and experiment has been studied by many workers with differing degrees of agreement[6, 10, 11, 12, 13, 14] and, in general, the agreement between theory and experiment is good considering the assumptions made and the uncertainty in property values. The values of R and R^1 give a true representation of the order of merit of materials and use of these parameters derived from individual property measurements to determine the thermal stress resistance of a particular simple shape should give a reasonable estimate of the behaviour of the material in service.

Ceramics Subject to Thermal Stresses

Table 1 lists the property values of significance taken from the literature[9, 9] together with calculated values of R and R^1 and the steady state maximum heat flux in two sizes of tube. In the majority of cases R is fairly constant up to 1 000°C and consequently the value at room temperature has been taken. Where R at 1 000°C varies widely from the room temperature value the value at 1 000°C has been included.

It will be noted that the oxide ceramics except fused silica, have a low value of R indicating a poor resistance to thermal shock under high heat transfer conditions. Fused silica, graphite, TiC and the nitrides of silicon and boron are all good under these conditions due to their relatively low expansion coefficients and high S_t/E ratio. The effect of a low expansion coefficient is marked for fused silica which has a vastly superior value of R. Of these materials graphite is the most promising as silicon nitride cannot be fabricated into a dense impermeable ware; there is a risk of devitrification with fused silica. At lower stress levels Al_2O_3, ZrO_2 and ThO_2 and siliconized silicon carbide may find some application.

The value of R^1 is of more significance for canning and fuel dispersion matrix materials which approach the steady state rather than the transient case. Under these conditions the order of merit is influenced by the conductivity value. Fused silica has only a moderate value of R^1 due to its extremely poor conductivity while BeO has a relatively good value especially at lower temperatures, due to its superior conductivity. The high conductivity of silicon carbide and its good high temperature strength gives a high value of R^1 to high temperatures. For this steady state case, graphite is superior to all the other ceramics. Silicon carbide is satisfactory as is BeO at low temperatures. At higher temperatures only graphite and SiC of the more conventional ceramics are able to withstand high heat fluxes.

Of the fissile materials the superior resistance of UC over UO_2 is evident in both the transient and the steady state cases.

Effect of Irradiation

The changes in mechanical and physical properties of ceramics on irradiation change the values of the parameters R and R^1 and consequently the thermal stress resistance. As indicated by Howie[18] the biggest property change is the fall in the thermal conductivity, and consequently the value of R^1, which is directly related to the maximum steady state heat flux, is affected most on irradiation.

The amount of experimental data available is extremely small, especially data on irradiation at elevated temperatures. It is known that irradiation damage tends to anneal out at high temperatures but Clarke and Williams[19] indicate that for high doses (~10^{22} nvt) an assumption that irradiation effects will

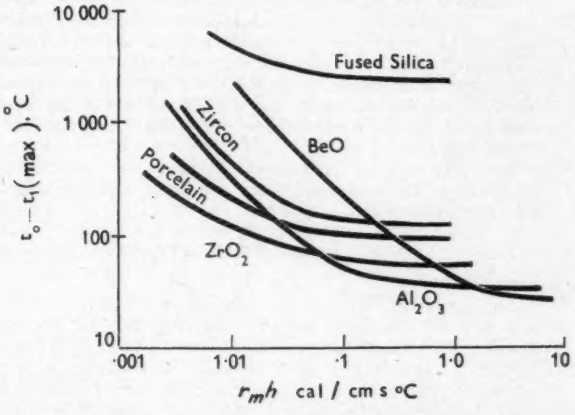

Fig. 4.—Curves for $t_o - t_1$ (max) against heat transfer parameter for various ceramics (after Kingery[1]).

TABLE 1

Material	S_t lb/in²	$E\times10^6$ lb/in²	$\alpha\times10^{-6}$/°C 20–1 000°C	$k\times10^{-2}$ cal/cm s°C			$R=S_t/E\alpha$ °C	$R^1=kS_t/E\alpha$, cal/cm s			Q max kW/ft 1 in o.d., 0·8 in i.d., Tube			Q max kW/ft 1 in o.d., 0·6 in i.d., Tube		
				25°C	400°C	1 000°C		25°C	400°C	1 000°C	25°C	400°C	1 000°C	25°C	400°C	1 000°C
BeO	6,200	40·7	(at 1 000°C)	48	20	7	17·7	27·6	11·8	1·24	163	66	7·3	37·5	16	1·68
	25,000	49·5	8·6				58·8									
MgO	26,900	45	13·7	11	4·5	1·6	42	4·62	1·90	0·67	27	11·2	4	6·25	2·58	0·91
Al_2O_3	36,000	52·7	8·5	9·2	3·1	1·5	81	7·5	2·5	1·21	44	14·7	7·1	10·2	3·4	1·64
SiO_2 (fused)	15,500	10·6	0·55	0·35	0·45	—	2 560	9	11·5	—	53	68	—	12·2	15·6	—
Stabilized ZrO_2	25,600	27·6	10·3	0·47	0·49	0·55	90	0·42	0·44	0·50	2·5	2·6	2·95	0·57	0·60	0·68
MgO. Al_2O_3	12,300	23	8·6	4·3	2·4	1·4	62	2·66	1·49	0·87	15·3	8·7	5·1	3·61	2·03	1·18
$3Al_2O_3$. $2SiO_2$	12,000	27·3	5·8	1.7	1·1	1	76	1·29	0·83	0·76	7·6	4·9	4·5	1·75	1·12	1·03
*Nuclear graphite (parallel)	2,400	1·5	2·9	29	17·4	10·2	550	160	89	56	930	520	330	219	172	77
Structural graphite (parallel)	5,800	2·65	2·3	12·2	7·9	4·8	950	116	75	46	675	440	275	158	102	63
*Structural graphite (perp.)	4,200	1	5·5	21	14	7·7	760	160	106	59	930	620	344	219	145	80
Siliconized SiC	24,000	56	4·4	27	17·3	10	97	26·1	16·9	9·7	153	100	57	35·5	22·9	13·2
Hot pressed TiC	110,000	45	7·5	7·3	3·5	1·3	326	23·8	11·4	4·25	140	67	25	32·4	15·4	5·76
Si_3N_4 78% dense	22,000	8·8	2·5	0·53	—	—	1 000	5·4	—	—	31·5	—	—	7·3	—	—
BN	15,000	12·4	2	3·6	3·4	3·2	600	21·6	R not constant		125	—	—	29·3	—	—
ThO_2	29,800	35	9·1	3·6	1·39	0·71	94	3·38	1·30	0·67	20	7·65	4·95	4·59	1·76	0·91
UO_2	25,000	31	10·4	2·36	1·38	0·82	78	1·82	1·08	0·64	10·8	6·4	3·75	2·46	1·47	0·87
UC	28,000	(at 1 000°C)	11·4	6·5	5·1	4·8	76	9·1	7·1	3·7	53.5	41·8	21·8	12·3	9·6	5.0
	50,000	31·5					140									

* Where extreme anisotropy occurs α, E and S_t are taken in one direction and k at right angles as the stress is perpendicular to the heat flow direction. Symbols indicate this direction relative to extrusion direction.

become less at higher irradiation temperatures may not be valid due to the agglomeration of defects which are less readily removed than single defects. However, the effect of agglomerated defects on the properties of the ceramic is likely to be less severe than when the defects are dispersed.

The thermal expansion coefficients seem to change very little on irradiation. Information available on the effects of irradiation on the strength and Young's modulus is sparse. With BeO irradiated at room temperature data are conflicting but the value of S_t/E does not appear to change appreciably[19]. The thermal conductivity decreases by 30% on irradiation at <100°C under doses of 10^{21} nvt; appreciable amounts of this damage anneal out above 250°C but some persists even at 1 400°C.

The only material where considerable data are available is graphite, where extremely large property changes occur on irradiation at 25°C[21].

The thermal conductivity of UO_2 has been estimated by Robertson *et al*[20] who showed that for high density material irradiated above 700°C the thermal conductivity was similar to that of unirradiated material, indicating that the damage anneals out at those temperatures. At lower temperatures (~100°C) the conductivity value was approximately 40% of the unirradiated value after an irradiation of 4 000 MWd/t. With UC, on the other hand, it has been estimated that a 58% decrease in the themal conductivity occurs on irradiation at 540–800°C[22] after 7 500–10 000 MWd/t.

No values of R on irradiation are given as it is assumed that S_t/E and α are unchanged on irradiation. Table 2 lists the information available.

NUCLEAR APPLICATIONS

Ceramic Fuels

For commercial reactors the most important property of any fuel is good irradiation stability with resulting high burn-ups. Another desirable property is a high conductivity which minimizes temperature gradients and allows the use of larger diameter elements without excessive centre temperatures. The thermal stress resistance of ceramic fuels is not very important as under the heat fluxes likely to be encountered in practice, cracking of the fuel will occur and the structural integrity will be maintained by the can.

The two uranium ceramics of greatest interest are UO_2 and UC both of which have good irradiation stability. The higher conductivity and uranium density of the carbide is an advantage but its oxidation resistance is inferior to that of the oxide. Other ceramic fuels of possible interest are US, UN and U_3Si_{12} but little data are available on these.

The structural integrity of the fuel element can be improved by dispersion of the ceramic fuel in a suitable matrix. Of the many possible ceramic matrices only graphite and silicon carbide can withstand the heat ratings suitable for commercial application. The most suitable element, based on graphite, is likely to contain uranium carbide or dicarbide as the dispersed phase. As regards silicon carbide matrices, the stable form of the uranium compounds compatible with silicon carbide is uncertain but the indications are that UC is compatible with SiC up to ~2 000°C.

Structural Materials

The heat ratings for fuel elements in gas cooled reactors being built in the U.K. are in the range 10–20 kW/ft. Table 1 indicates that for a thin walled tube (0·1 in wall) at 1 000°C only graphite, silicon carbide and titanium carbide can withstand greater fluxes and titanium carbide cannot be readily fabricated into long tubes. Silicon carbide, while not withstanding such high heat fluxes as graphite has a much greater strength up to 1 000°C; it can withstand oxidizing atmospheres to temperatures above 1 000°C, and it has a moderately low thermal neutron absorption cross section.

TABLE 2

Material	Temp.	Dose	$k\times10^{-2}$ cal/cm s °C After Irradiation	R^1 cal/cm s After Irradiation	R^1 Before Irradiation
BeO	<100°C	7×10^{19} nvt	32·0	18·6	27·6
Al_2O_3	<100°C	4×10^{20} nvt	3·0	2·4	7·5
MgO Al_2O_3	<100°C	4×10^{20} nvt	2·2	1·34	2·66
Graphite	25°C	4×10^{20} nvt	1·2	6·6	198
Graphite	100°C	4×10^{20} nvt	2·1	11·6	180
Graphite	180°C	4×10^{20} nvt	8·0	44·0	170
UO_2	<100°C	—	·94	·73	1·82
UO_2	<700°C	—	1·1	·86	·86
UC	..700°C	—	2·0	2·8	7·1

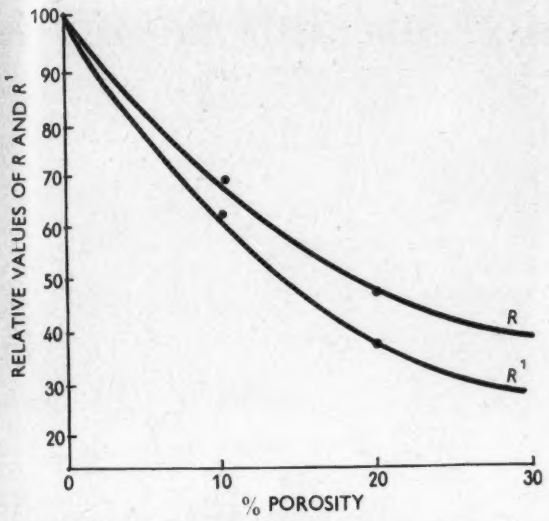

Fig. 5.—Variation of R and R^1 with porosity calculated from the predicted variation of S_t, α, E and k with porosity[9].

Control Materials

Boron compounds are good absorbers but boron yields lithium and gaseous helium on neutron capture. B_4C is a good ceramic control as it has sufficient void space in its lattice to accommodate the helium at temperatures below 1 500°C. Boron nitride is also a possible control material.

Of the rare earth elements, europium, gadolinium and samarium, which have high cross-sections, europium is the most promising. in the form of europium oxide.

While control rods have to withstand rapid temperature changes of a transient nature, the lack of property data makes accurate predictions of the thermal shock resistance of ceramic control materials rather difficult. However, as regards boron nitride, its high thermal shock resistance is likely to be offset by its poor mechanical properties. The rare earth oxides have low strengths and high expansion coefficients which will give low values of R and poor thermal shock resistances.

It would appear likely that for low temperature applications (~700°C) ceramic dispersions in metal matrices would be suitable. At higher temperatures dispersion of absorbers in materials having a good resistance to thermal shock (high values of R, see Table I), i.e. silicon nitride, silicon carbide, graphite or refractory metals are possibilities.

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The Soviet Exhibition

AIMED primarily at the general public, the nuclear energy section of the Soviet Exhibition at Earls Court in London (July 7-29) was none-the-less interesting to technical visitors, particularly as the Soviet Union had taken the trouble to man the stands with representatives with experience of nuclear energy development. The principal centre of attraction was a model of the *Lenin* cut away to show a simulated reactor system rather than an accurate model. The nuclear programme has been subject to a number of cuts and, for example, both the Beloiarsk and the Novo-Voronesj stations are committed to only half the capacity originally envisaged. Models of these reactors were displayed.

The Beloiarsk station will now comprise two reactors, each of 100 MW electrical output, based on the graphite moderated, water-steam cooled system. This reactor is the logical development of the first 5 MW power station which began operation in 1954, and the first unit is nearly complete. The reactor itself contains approximately 1 000 fuel channels, two-thirds of which are cooled by boiling water, and one-third by steam. The fuel, of initial enrichment 1.3%, is an 8% uranium-molybdenum alloy with magnesium additions, canned in stainless steel and designed for a core life of 730 days. The steam and water channels are mixed throughout the reactor, and in both cases flow is down a central plain tube, to a manifold where it divides, to pass upwards through six hollow fuel elements arranged symmetrically around the down-comer. Primary coolant enters the boiling tubes at 300°C and leaves at 340°C at a pressure of 155 atm. The steam-water mixture, containing 33% steam, passes through a separator, from which the steam is fed to a heat exchanger and re-cycled back to the reactor. The secondary feed to the heat exchanger comprising a water-steam mixture (20% steam) passes to the reactor superheating tubes at a temperature of 215°C, where it is raised to 510°C at a pressure of 110 atm.

At Novo Voronesj, where originally two PWRs, each of 210 MW, were to be installed, only one is now firmly scheduled and under construction. It is conceivable that at a later date this will be modified to a BWR but only after experience has been obtained on it as a PWR and the dual cycle 50 MW BWR being built at Ulyanovsk, will decisions be taken. The BWR is designed to operate at the same pressure as the PWR (100 atm) with the same fuel elements (UO_2 canned in a zirconium-niobium alloy) and the same basic structure.

Also at Ulyanovsk, is to be constructed the B H-50, the 50 MW fast reactor, cooled by sodium, with a sodium secondary circuit feeding a sodium to water heat exchanger with a static mercury barrier, based on the B P-5 5 kW experiment. The main parameters of these plants were first discussed at the Geneva Conference (see also *Nuclear Engineering*, Oct., 1959).

At the same establishment the sodium graphite reactor is under construction, designed to follow closely, technologically, the construction of the fast reactor. Two sodium coolant loops act as primary coolant, and uncanned graphite as the moderator.

Reference was made at the exhibition to the Siberian 600 MW (6 x 100 MW water cooled graphite moderated reactors) power station, the first unit of which began operating in Sept., 1958.

The thermonuclear exhibit comprised some of the equipment shown at Geneva, including a model of Ogra.

Vacuum Melting Research in Australia

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and M. E. HARPER,
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Describes a special design of vacuum furnace, its installation, commissioning and future programme.

FUEL element development by the Australian Atomic Energy Commission necessitated a research programme in metal fabrication techniques, particularly vacuum melting and casting. In 1955/6 it was decided to purchase a furnace which, in addition to routine melting of uranium, would possess sufficient flexibility to enable a wide range of research to be carried out. At the time, senior staff of the A.AEC were stationed at AERE, Harwell, and the general specification of the furnace arose from the experience gained there. The main requirements were:—

(1) To be capable of melting and casting the " reduction billets " of uranium produced by U.K.AEA, Springfields. These billets weighed some 100 kg but to allow for expansion a capacity of 150–200 kg was specified for the furnace.

(2) To be sufficiently flexible in design to allow other operations to be carried out in the vacuum chamber, e.g., vacuum melting, casting, sintering, consumable and non-consumable arc melting, if required, and to be equipped with auxiliary ports to which attachments could be made as required for these operations.

(3) To be capable of reaching a temperature of 1 800°C, allowing most uranium alloys to be melted and cast. A power supply of 100 kW on a 10 in diameter by 16 in graphite crucible was specified.

(4) To contain a vacuum pumping system capable of reaching an ultimate pressure of 10^{-6} mmHg; the speed of the pumps in the range 1–100μ to be sufficient to cope with large release of dissolved and entrained gases expected during operations. Four thousand litres per second at 10^{-3} mmHg and 6 000 l/s at 10^{-4} mmHg was specified. (Although an ultimate pressure of 10^{-6} mmHg is not required for uranium melting, many of the research projects contemplated for the furnace would require this limit.)

(5) To be constructed to minimize contamination from radioactive and toxic materials which may be melted in the unit and to allow decontamination with safety when required.

The more unusual features were the flexibility required, the provision of fast pumping in the intermediate range where conventional mechanical or diffusion pumps would be relatively inefficient, and the provision of bottom pouring.

General Design

The general design of the furnace, which was supplied by Efco-Edwards High Vacuum Metallurgy Ltd., is summarized in Table 1. The furnace vessel, double-walled for water cooling, is fabricated from polished stabilized stainless steel, for ease of decontamination.

Fig. 1 shows a simplified section of the furnace with the induction heating coil and crucible in the centre of the vessel with the water-cooled mould vessel beneath. The crucible is arranged for bottom pouring, the hole being sealed by a hemispherical stopper which is separately cooled and " freezes " a plug of metal in the pouring hole; when casting, the stopper is swung out of the way by an external mechanism and the plug is allowed to melt. If necessary, lip-pouring crucibles may be used by the addition of a standard trunnion and coaxial seal tilting mechanism, the furnace being provided with a blanked-off port for this purpose. Smaller crucibles and special-purpose heating coils may be fitted, if required.

In addition to this blanked-off port, there are three viewing windows with internal wipers and radiation shields;

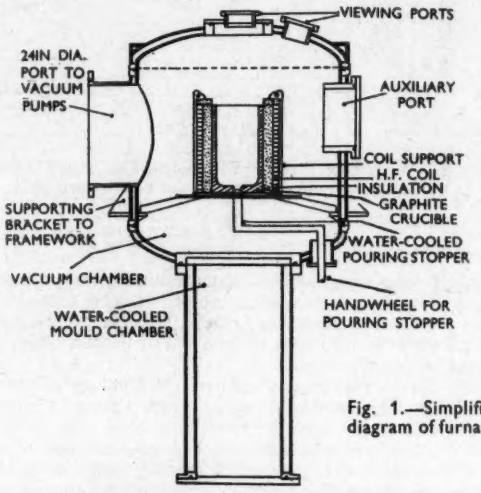


Fig. 1.—Simplified diagram of furnace.

one window is placed in the middle of the lid, and can be replaced by an electrode for arc melting.

The lid of the vacuum chamber is sealed to the body with an O-ring seated in a trapezoidal groove, and is lifted clear of the furnace by synchronized hydraulic jacks which raise two rails under the lid, allowing it to run clear.

The mould chamber is similarly sealed to the furnace chamber by O-rings and held in place by four clamps. It is raised and lowered by a hydraulic jack platform sited below the chamber. Provision is made for heating the moulds when required.

Pumping System

A 24-in port in the side of the furnace chamber connects to the cruciform manifold of the vacuum pumping system, from which a 6-in valved branch is directly connected to a Kinney GKD 310 air-ballasted rotary pump with a free air displacement capacity of 310 ft^3/min (8 700 l/min) capable of attaining an ultimate pressure of 10^{-2} mmHg in the chamber. On full air ballast, the pump can handle 20-30 lb/h water vapour without serious contamination of the oil. This unit is used for " rough " pumping and backing.

The fast pumping speed at intermediate pressures is achieved through a 4-stage oil vapour booster diffusion pump (Edwards Speedivac 30B4) connected to the manifold via a refrigerated baffle and 16-in baffle and isolation valve. This pump has an ultimate pressure of less than 10^{-4} mmHg; the peak unbaffled speed is 4 500 l/s of air from 10^{-3} to 10^{-1} mmHg and the peak baffled speed better than 3 000 l/s over the range 10^{-2} to 10^{-1} mmHg. These pumping speeds ensure that the chamber pressure can be

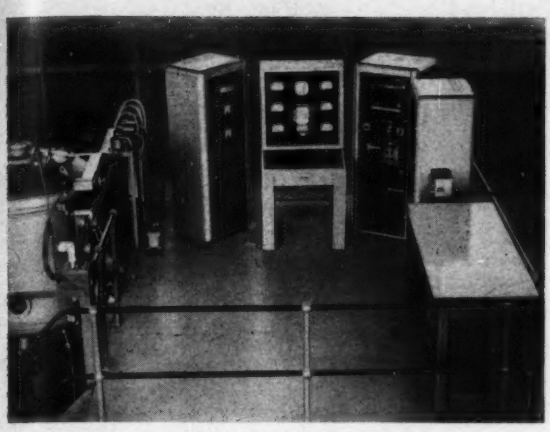


Fig. 2.—Operating platform with control gear.

controlled below 0·1 mmHg during melting even though severe outgassing may occur. (In some instances, of course, the chamber pressure may be made to rise above this limit to minimize eruption of the molten metal by excessive outgassing.) The vapour jet on the high vacuum side of the booster pump is designed primarily as in a conventional diffusion pump, the low vacuum jets operating more as ejection units allowing high throughputs to be attained over a wide pressure range.

The two fractionating oil vapour diffusion pumps (Edwards Speedivac F1605) are connected in parallel to the manifold through 16-in baffle valves. Each pump has an unbaffled capacity of 5 000 l/s between 10^{-3} and 10^{-5} mmHg with an ultimate pressure of less than 5×10^{-7} mmHg; the baffled speed on each pump is 3 000 l/s over this range. The diffusion pumps are backed by a small oil vapour booster pump (Edwards Speedivac 9B1) and the Kinney rotary piston pump. The inclusion of the small booster pump enables the diffusion pumps to operate in parallel with the 30B4 booster pump at a common backing pressure. A small rotary mechanical pump (Edwards Speedivac 1S150) is also incorporated to hold the diffusion pumps under vacuum whilst not connected to the chamber system.

Air admittance and gas admittance valves are connected to the manifold adjacent to the main chamber; thus the furnace may be operated with a controlled pressure of inert gas or let to atmospheric pressure for charging or unloading as required.

Power Supply

High frequency power for the induction coil is obtained from a 100 kW 2 850 c/s single-phase motor generator situated in an annexe adjacent to the main building. The generator is of the heteropolar type, direct coupled to a 160 h.p., a.c. drive motor by a common shaft. The generator is cooled by forced air circulation through an air-water heat exchanger. Output from the generator may be switched through series and parallel capacitors of 1 250 kVAr capacity to the furnace or to an adjacent heater station as described below.

The furnace induction coil, 16 in diameter × 18 in high, is a parallel arrangement of 30 turns of copper tube, lined with an alumina-calcium penta-aluminate cement. The gap between this lining and the crucible is filled with powdered graphite or alumina, depending primarily on the operating temperature.

The heater station serves as a general outlet for high frequency power in the laboratory and is required to handle a range of coil designs at various powers, and a variable-ratio transformer of 100 kW capacity is included for coils of low inductance; full busbar voltage (250 V) is available through an alternative outlet when required.

Instrumentation and Controls

Particular attention has been given to adequate instrumentation and controls and the layout of equipment, the main control desk being situated on the operating platform adjacent to the furnace body.

The controls for all the high frequency equipment, including the main contactor, generator output, and sequence switching of the power factor correction capacitors, are located at the right, together with overvoltage and overcurrent relays and indicating lights showing circuit faults. Failure of cooling water on the furnace coil or capacitors, or excessive temperature on the generator, will cause the main contactor to trip; there are also a number of mechanical interlocks associated with this warning system.

TABLE 1. Furnace Specification

Furnace	
Capacity	200 kg U (bulk equivalent 200 lb steel)
Maximum temperature	1 800°C
Construction	Water-cooled, stainless steel jacket
Size	48 in i.d. × 52 in high
Crucible size	10 in i.d. × 16 in high
Mould chamber	18 in i.d. × 48 in long
Power Supply	
Type	Single-ph. motor generator, 100 kW (1·0 p.f.) 250 V ± 10%, 490 A, 2 850 c/s synchronous speed
Load capacitors	1 250 kVAr paper dielectric type, with automatic switching in steps of 75/150 kVAr
Cooling water	20 gal/min at 10 psi
Vacuum Pumps	
Roughing and backing	Kinney GKD 310, 8 700 l/s, 10^{-3} mmHg ultimate
Booster	Edwards 30B4, 4 500 l/s, 10^{-4} mmHg ultimate
Diffusion pump	(2) Edwards F1605, 10 000 l/s at 10^{-4} mmHg, ultimate 5×10^{-7} mmHg
Maximum power requirements	68 kW
Cooling water	30 gal/min at 20 psi

The high frequency coil is earthed through earth leakage sensing equipment; when the insulation resistance of the H.F. system to earth fails, the leakage upsets a bridge circuit in the sensing equipment and the out-of-balance current trips the main contactor through an auxiliary relay. Provision is made for "desensitizing" or cancelling the leakage detection system as, for example, when a new furnace lining is being prepared, and moisture on the coil may temporarily cause minor earth leakage.

Controls for the vacuum pumping system are mounted on the left of the desk. Above these are mounted thermal conductivity (Pirani) and cold cathode (Penning) gauges connected to gauge heads at various positions in the system to indicate pumping conditions. One Pirani head indicates pressure in the line immediately before the GKD 310 rotary pump and one is connected to the 24-in manifold adjacent to the main chamber, to indicate pressures from 10·0 to 0·001 mmHg. The Penning head is also connected to the 24-in manifold on the furnace and indicates pressures from 0·005 to 0.0001 mmHg. A Bourdon gauge is connected to the main chamber to indicate pressure during initial evacuation or for the admission of a controlled amount of inert gas if required by the process.

The furnace and other metal processing equipment is contained in a laboratory 120 ft × 50 ft serviced by a 5-ton crane at a height of 30 ft. The motor generator, and its associated switchgear, are housed in an annexe; high frequency busbar is run in floor ducts with non-conducting covers.

All cooling water from the furnace is recirculated through a forced-draft cooling system with a capacity of 400 000 Btu/h, situated outside the annexe. An emergency guaranteed water supply is provided in the event of failure of a recirculating pump during melting.

Bottom Pouring

The device adopted was the result of a considerable amount of work at Edwards, prior to the Australian contract, to develop a method which would eliminate the chief disadvantage of existing techniques—the use of plugs and rods which required grinding-in between successive melts—and enable resealing in a hot crucible without breaking vacuum. Work was carried out on a 56 lb. (steel) capacity furnace, which was modified to contain a mechanism that was, incidentally, almost identical with the final arrangement.

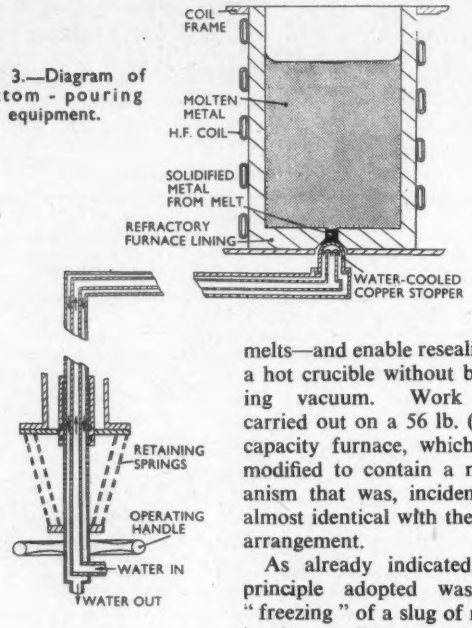


Fig. 3.—Diagram of bottom-pouring equipment.

As already indicated, the principle adopted was the "freezing" of a slug of metal in the crucible tap-hole, by means of a water-cooled movable stopper. This, a copper hemisphere, was only required to make line contact with a chamfer at the base of the orifice which had an inner diameter larger than the pouring hole of the crucible. As melting commenced, the initial liquid metal from the charge immediately froze on contact with the copper plug and a solid plug of charge metal was built up in the pouring hole and maintained solid throughout the melt by the cooling action of the copper stopper. After the termination of vacuum refining, the stopper was withdrawn and swung clear of the pouring orifice, there being no sticking of the frozen metal to the copper surface. A time delay then occurred whilst the plug was melted out by conduction from the charge. Immediately pouring had ceased, the stopper was swung back into position and external springs lifted it back into contact with the orifice. In all the trials carried out it was always possible to reseal first time and leakage on a subsequent melt was never experienced.

To simulate the melting conditions for uranium, graphite crucibles were employed and copper charges melted. The use of the graphite crucible, which also acted as a susceptor, considerably helped in keeping the melting-out time of the stopper to within the region 10 to 30 seconds.

To investigate the possibilities of the use of this technique with other metals, experimental work was extended to the melting and bottom pouring of ferrous and nickel base alloys in conventional refractory linings. The linings were rammed in the normal manner around a pre-formed central core and fritted by the graphite former method. The central core was cast around a wooden former, turned to the shape of the bottom pouring orifice described, using a refractory mix consisting of the conventional lining material bonded with calcium penta-aluminate cement. This set extremely well and the cast surface after the wooden former had been removed did not require any grinding and pre-firing was found to be unnecessary.

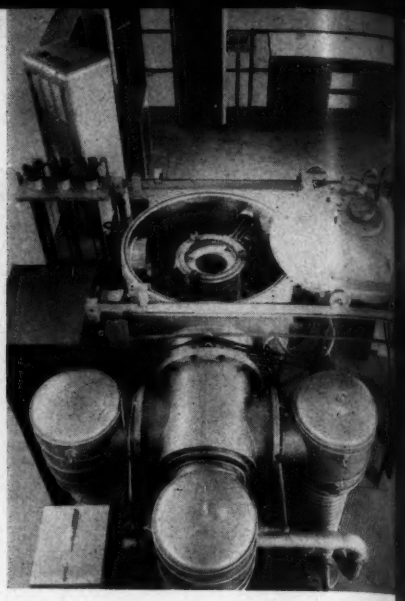


Fig. 4.—General view of installation from above the furnace, showing exhaust manifold and pumps.

As to be expected, the time for pouring to commence after retraction of the stopper varied widely with the dimensions of the orifice as all of the heat for melting-out was required to be conducted from the molten charge. It was found inadvisable to make the length of the pouring hole too short, as a minimum delay of 5-10 seconds was required before pouring, to ensure that the stopper mechanism could be swung clear, and this could not be guaranteed with varying pouring temperatures. To overcome this the length was increased and consistent times obtained by incorporating a graphite ring in the base of the lining. This materially helped in supplying heat for the melting-out operation, and it was positioned so that its temperature, under induced effect, was less than the temperature at which a carbon reduction of the lining material employed could take place. Use of this technique was perfectly satisfactory and melting-out times of the same order as those obtained with graphite crucibles were achieved. Again, very clean pouring was obtained, resealing was effective and leakage did not occur.

Initial Operation and Commissioning

After installation of the furnace the coil and associated lining were dried out at low power for several days whilst checks were made upon the performance of the pumps and the power supply equipment. The ultimate pressure obtained in the furnace with all pumps connected was less than 10^{-4} mmHg, and leak tests were carried out by the pressure rise technique extending over a period of 20 hours. With the pumps isolated, the pressure rose to 5×10^{-3} mmHg, corresponding to a leak rate of 0·1 lusec. With the pumps connected to the furnace, but turned off, and with the pumping lines isolated from the rotary mechanical pump, the pressure of the whole system rose to 7×10^{-3} mmHg in the same time, corresponding to a leak rate of 0·15 lusec.

In order to commission the furnace initial melts of copper were made in graphite crucibles, this procedure being adopted to simulate as closely as possible conditions which would pertain for the "active" commissioning of uranium melting. Graphite and conventional steel moulds were employed, dressed with magnesia plus 1% sodium silicate and dried at approximately 150°C, to provide ingots 4 in dia. × 18 in, 4 in sq. × 18 in and $1\frac{3}{16}$ in dia. × 36 in

long. The charges of deoxidized copper varied in weight from 120-280 lb, depending on the mould used. Initial evacuation of the furnace was carried out over a period of 20-30 minutes to prevent loose-packed insulation around the graphite crucible being disturbed. The booster pump was brought into operation at 2 mmHg and a pressure of 10^{-2} mmHg obtained in less than one minute. A power input of 30-50 kW attained a temperature of 1 100°C in 40-50 minutes. The pressure was maintained steady at 10^{-2} mmHg up to 900°C and rose slightly during melting. After termination of gas-generating reactions when all the metal had been melted, the temperature was increased and, if necessary, the diffusion pumps brought into circuit to add to the speed of the booster pump. The amount of superheat applied varied with the section of the cast to be made and was in the range of 1 400°C for the $1\frac{3}{16}$ in dia. rods and 1 300°C for the 4 in bars. When the melt was ready for casting, the water-cooled stopper was removed and pouring effected. With a $\frac{1}{2}$ in orifice a time delay of 15 seconds was experienced for a melt temperature of 1 400°C and for a $\frac{5}{8}$-in orifice the delay was 20-25 seconds. The pouring time for 120 lb melts was 15-20 seconds and approximately 30 seconds for the 280 lb melts. After pouring, the diffusion pumps were isolated and the booster pump maintained operating for some 10-15 minutes before isolation.

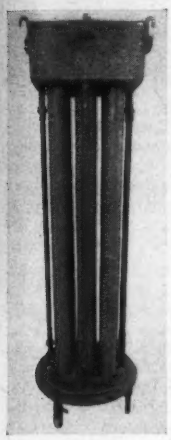


Fig. 5.—Graphite mould assembly.

During the trials of copper melting, it was necessary to carry out minor modifications to the water recirculation system and bottom stopper. Also checks were made on the temperature variation in the furnace, by thermocouples placed in the crucible, one at the base near the pouring orifice, and a second near the top of the crucible wall. In addition, the immersion pyrometers were used to obtain the melt temperature and an optical pyrometer measurement was made as a check. Although there is no obvious interference from the cooling of the stopper, a considerable temperature variation, i.e., about 300°C, exists between the crucible wall and the crucible bottom, where the temperature measurement is made approximately $\frac{1}{2}$ in below the metal level. Further work was scheduled to be carried out on temperature distribution to arrive at the optimum point for controlling and recording melt temperature conditions. The immersion pyrometers, fitted with graphite sheaths, were only suitable for 4-6 immersions and are, therefore, considered only as check methods immediately prior to pouring.

Uranium Melting

"Active" commissioning was carried out with a 180 kg charge of uranium cast into 4 in dia. × 18 in long moulds. Following this, more general work was carried out on the casting of 7 in spheres for radiation shields and 1·050 in dia. × 36 in long bars for a sub-critical assembly. In both cases, the mould material was graphite dressed with magnesia plus $\frac{1}{2}$% sodium silicate to prevent metal attack. In the case of the bars the mould consisted of a cluster of nine. This mould is illustrated in Fig. 5, where the general details of the hot top and feed can be seen. The moulds are dried but not fully outgassed before use and with the present design no trouble has been experienced with shrinkage cavities or pipes.

For these melts, the furnace is charged with 130-150 kg of metal in the form of reduction billets or recycled hot-tops. Starting from cold at a pressure of less than 5 μ with the booster only in operation, the charge is heated until a temperature of approximately 1 000°C is reached, at which stage the power is increased to 50 kW until the charge melts. There is very little gas evolution on melting and superheating to the pouring temperature, 1 400°C for the 36 in rods and 1 350-1 370°C for the spheres, is carried out with a heating power of 60 kW. Temperature control is carried out from two thermocouples in the crucible walls and a final check is made by immersion pyrometer immediately prior to pouring. The positions of the two control thermocouples, one in the wall and one in the base of the crucible, provides two different temperature readings and experience has shown by the use of the immersion pyrometer that the true metal temperature is the mean of these two thermocouple readings. During the latter stage of superheating, control on the wall thermocouple is set to ensure that the crucible temperature does not rise above 1 500°C. The heating is continued under these conditions until the pouring temperature is reached. The heating cycle occupies some $1\frac{1}{2}$-2 hours, during which the chamber pressure rises from 5 μ to 30-40 μ at melting. After melting, the pressure drops to 20-30 μ and this can be decreased from 5-10 μ if required by the addition of the diffusion pumps.

Future Work

Although the furnace is committed to certain production requirements of uranium melting, a programme of future work has already been initiated. A theoretical assessment of heat transfer conditions across various mould interfaces was made on the assumption that there was negligible heat loss from the mould as its base was insulated against conduction and, as the operation was carried out in vacuum, loss by convection was negligible. A practical investigation revealed that heat losses were far from negligible and careful plotting of all mould temperatures is now in progress. Already it has been found practicable to find the point of solidification in some moulds by the release of latent heat. This has led to further extensions in work from which it is hoped finally to relate mould interface conditions with the properties of some castings, particularly those which show segregation.

Further work is to be carried out on mould design, particularly in respect to the lengthening of mould life by improved tundish arrangements, as some erosion of moulds has been experienced where the parts are directly subjected to the molten stream. Although there appears to be very little attack on the graphite moulds even without dressing, it is anticipated that the total cycle time can be considerably reduced, particularly in the case of standard cast sections, by the use of steel moulds. These are desirable to increase mould life and decrease costs but their satisfactory employment will depend upon the ability to find a suitable mould dressing.

It is anticipated that a correct study and organization of operator's duties will, with the considerable power input available, enable the overall cycle time to be reduced to one hour or less.

Acknowledgments

The authors wish to thank the Australian Atomic Energy Commission and the directors of Edwards High Vacuum, Ltd., for permission to publish this paper.

TRANSLATIONS

Trawsfynydd.

Atomic Power Constructions, Ltd. vient de terminer sa second année d'activité sur le chantier de la centrale nucléaire que cenconsortium construit pour le compte du Central Electricity Generating Board, dans le nord du pays de Galles. Trawsfynydd est la première centrale nucléaire britannique qui soit située à l'intérieur des terres. Il en est résulté quelques difficultés pour le transport de l'équipement. International Combustion, Ltd. l'in des entrepreneurs principaux a décrit récemment quelques unes des méthodes mises au point pour amener les viroles des échangeurs de chaleur au chantier.

Le traitement des déchets liquides de faible activité.

Lors de l'exploitation des réacteurs gaz-graphite anglais, les déchets radioactifs liquides apparaissent principalement lors de la corrosion des gaines de magnox dans les piscines de refroidissement des éléments de combustible. Zn^{65} est l'isotope principal qui apparait lors de cette corrosion; à raison de 80%, il forme des composés insolubles qui peuvent être évacués par enlèvement de la boue qui s'accumule au fond de la piscine. A Berkeley et à Bradwell, cette bove est traitée par échanges d'ions. Ce processus est décrit et comparé avec l'équipement plus souple installé dans les laboratoires nucléaires de Berkeley. Les matériaux utilisés pour la construction des revétements superficiels de la centrale nucléaire de Berkeley sont décrits en détail.

L'analyse des contraintes des orifices à pourtour renforcé dans les récipients sous pression.

Des concentrations de contraintes importantes se produisent partout où il y a discontinuité de pression ou là où des charges supplémentaires sont appliquées par l'emploi d'accessoires supplémentaires. Les contraintes sont dues le plus communément aux ouvertures pour raccords, supports et modifications de la forme géométrique. Le présent article traite du calcul des contraintes qui se manifestent dans les ouvertures renforcées par anneaux et bords combinés.

La résistance aux contraintes thermiques des céramiques.

Les autres caractéristiques physiques des céramiques ont été discutées dans quatre articles précédents. Les conclusions qui suivent se rapportent aux gradients de température qui créent des contraintes et peuvent finalement provoquer la rupture d'une piéce d'équipement. Ces contraintes peuvent être permanentes ou passagères. L'auteur classe les différents types de céramiques en fonction de leur comportement tel qu'il est prédit par la théorie.

Recherches sur la Fusion sous vide en Australie.

La Commission d'Energie Atomique Australienne a inauguré un laboratoire pour les recherches dans les techniques de fabrication des métaux associées au développement des éléments combustibles nucléaires à intégrité élevée. Un des appareils les plus importants dans ce laboratoire est représenté par un four de fusion et de coulée sous vide à induction à haute fréquence ayant une capacité d'environ 200 kgs d'uranium. Les besoins et la description de ce four sont indiqués en détail et on y traite particulièrement des travaux de développement effectués à l'égard de la nouvelle technique de versement par le fond employée dans ce four.

Trawsfynydd.

Atomic Power Constructions Ltd. haben jetzt gerade das zweite Jahr beim Bau des Atom-Kraftwerks vollendet, das sie für das CEGB in Nord-Wales in Arbeit haben. Trawsfynydd ist das erste britische Atom-Kraftwerk, das im Inland gelegen ist, und die Lage hat gewisse Schwierigkeiten des Materialtransportes gerade wegen dieses Umstandes mit sich gebracht. International Combustion Ltd. sind unter den Haupt-Bauunternehmern und sie haben kürzlich einige der Methoden dargelegt, die sie angewendet haben, um Kesselringe an die Baustelle zu transportieren.

Die Behandlung von flüssigen Abfallstoffen mit geringer Aktivität.

Bei den Magnox Reaktoren entstehen flüssige Abfallstoffe in der Hauptsache in den Kühlbassins für die Elemente durch Korrosion der Magnox-Brennstoffmäntel. Das Haupt-Isotop ist Zn^{65}, von dem mindestens 80% in der Form von unlöslichen Verbindungen anfallen, die durch Vakuum-Abfallreinigung des Bassin-Bodens entfernt werden können. In Berkeley und Bradwell wird ein Ionen-Austausch-Verfahren angewendet, das beschrieben wird, und dem die Behandlung in einer mehr anpassungsfähigen Anlage gegenübergestellt wird, die in den Atom-Laboratorien von Berkeley eingerichtet ist. Es wird weiter ein detaillierter Bericht über die Materialien gegeben, die als Oberflächenschutz bei dem Bau des Kraftwerks Berkeley und auch an anderen Stellen Verwendung gefunden haben, um die Entgiftung zu erleichtern und zu verhindern, dass sich Aktivität bildet.

Festigkeitsuntersuchungen der Randverstärkten öffnungen von Druckgefässen.

Bedeutende Spannungsanhäufungen treten dann auf, wenn Druckungleichmäfsigkeiten vorkommen, oder wenn durch den notwendigen Anbau anderer Teile zusätzliche Belastungen auftreten. Erhöhte Spannung werden am häufigsten verursacht durch Abzweigöffnungen, Stützen oder Anderungen der geometrischen Form. Dieser Artikel befafst sich mit der Berechnung von Belastungszuständen in Offnungen mit kombinierten Rand- und Ringverstärkungen.

Keramische Materialien-Widerstand gegen thermische Beanspruchung.

Vier frühere Aufsätze befassen sich mit anderen physikalischen Characteristiken der keramischen Materialien. Diese Schlussbetrachtungen hier betreffen die Temperaturdifferenzen, die übermässige Beanspruchungen hervorrufen und schliesslich zum Versagen eines Werkteiles führen können. Die Beanspruchungen können vorrübergehend auftreten oder ständig vorhanden sein, und der Autor bringt Listen in Gestalt von Tabellen, in denen das Verhalten der verschiedenen Arten von keramischen Materialien theoretisch vorausgesagt wird.

Forschungsarbeiten über Vakuumschmelzen in Australien.

Die australische Atomic Energy Commission hat zur Erforschung der Metallschmelzverfahren im Zusammenhang mit Entwicklung von hochwertigen Spaltstoffelementen ein Laboratorium eingerichtet. Eine der wichtigsten Anlagen dieses Laboratoriums ist ein Hochfrequenz-Induktions-Schmelz-und-Giefsofen mit einem Fassungsvermögen von etwa 200 kg Uran. Der Ofen ist im einzelnen beschrieben, und zwar mit besonderer Betonung der Entwicklungsarbeit für Einführung neuartigen Bodengiefstechnik, die bei diesem Ofen zur Anwebdung kommt.

Trawsfynydd.

Atomic Power Constructions Ltd., acaban de terminar su segundo año de labores sobre la central de fuerza nuclear que están construyendo para CEGB en País de Gales del Norte. Trawsfynydd es la primerca central nuclear británica a ser situada en el interior del país, y el sitio ha posado algunas dificultades en la transportación de materiales debido a su situación. Recientemente, International Combustion Ltd., uno de los principales contratistas, explicó algunos de los métodos que adoptaron para transportar virolas de caldera al sitio.

Manipulación de Desperdicios de Líquidos de Baja Actividad.

Con los reactores "magnox," el efluente líquido surge principalmente en los charcos de enfriamiento de elementos por la corrosión de los recipientes de combustible "magnox." El isotopo principal es Zn^{65}, del cual el 80% po lo menos está en la forma de compuestos insolubles los que pueden ser removidos por limpeiza al vacío del lodo en el fondo del charco. El tratamiento en Berkeley y Bradwell es mediante un procedimiento de intercambio de iones que se describe y se contrasta con la planta más flexible instalada en los laboratorios nucleares de Berkeley. Se ofrece tanbién un relato detallado de los materiales empleados como acabados de superficie en la construcción de la central de fuerza de Berkeley y otras partes para simplificar la descontaminación y evitar el crecimiento de actividad.

Análisis de Esfuerzos de Tensión de las Aberturas Reforzadas con Borde en Recipientes de Presión.

Ocurren importantes concentraciones de esfuerzos dondequiera que haya una descontinuidad en una presión o donde son aplicadas cargas adicionales mediante los accesorios necesarios. Los generadores más comunes de esfuerzos son aberturas bifurcadas, soportes y cambios de forma geométrica. Este artículo trata con el cálculo de la generación de esfuerzo en aberturas reforzadas de borde y anillo combinados.

Ceramica—Resistencia al Esfuerzo Termico.

Cuatro artículos anteriores han discutido otras caracteristicas de productos cerámicos. Estas observaciones finales se relacionan con gradientes de temperaturas que originan esfuerzos y a las largas conducen a la falla dell componente. Los esfuerzos pueden ser transsitorios o una condición firme y el autor ofrece una lista, en forma tabulada, de las predicciones teóricas para el comportamiento de diferentes tipos de productos cerámicos.

Investigaciones Sobre Derretimiento al Vacio en Australia.

La Comisión Australiana de Energía Atómica ha inaugurado un laboratorio para investigar técnicas de fabricación de metales asociadas con el desarrollo de elementos nucleares de combustible de elevada integridad. Uno de los principales renglones de equipo en este laboratorio es un horno para fundir y derretir al vacío de inducción de alta frecuencia, con una capacidad de unos 200 kg de uranio. Las exigencias y descripción de este horno son detalladas y se hace hincapié particularmente sobre el trabajo de evolución llevado a cabo con relación a la nueva técnica de vaciado por el fondo empleado con este horno.

Personal

Appointments—U.K.

Mr. B. C. Pyle, formerly assistant chief project engineer, CEGB, Northern Project Group, as assistant chief project engineer, Southern Project Group, in succession to **Mr. W. B. Shannon,** who has retired. Succeeding Mr. Pyle in the Northern Group is **Mr. D. A. Pask,** project engineer with the Southern Group. From 1954-57 Mr. Pask was deputy resident mechanical and electrical engineer and then deputy resident engineer at Calder Hall.

Lt.-General Sir William Stratton, vice-chief of the Imperial General Staff, 1957-60, as chairman of Edwin Danks and Co. (Oldbury) and of Penman and Co., both members of the Babcock and Wilcox group. **Mr. A. D. Thomson,** head of the Babcock and Wilcox atomic energy commercial section, as managing director of Edwin Danks, and **Mr. C. G. H. Hayward,** general manager of the company's combustion division, and **Mr. H. Harding Smith,** general sales manager, to the board.

Mr. F. Mullery, head of English Electric's welding laboratory at Whetstone, as chief engineer of the company's newly formed Welding Equipment Division (see "Industrial Notes"). Division manager is **Mr. R. H. Broughton,** formerly head of the company's welding sales department.

Mr. H. G. Nelson, managing director of English Electric, as a director of the Bank of England.

Sir Noel Hall, principal of Brasenose College, Oxford, and a director of Fisons, to the board of Babcock and Wilcox. Also as a director, **Mr. L. W. Cole,** who has been with the company for 32 years and secretary since 1952.

Mr. T. Carlile, general manager of the Babcock and Wilcox works at Renfrew, Dalmuir and Dumbarton, as general manager. He succeeds **Mr. D. D. Cruickshank,** who has retired.

Mr. K. D. Starr, chief engineer and a director of The British General Electric Company of Central Africa, as manager of GEC's Witton export sales department.

Dr. R. L. Doan

Mr. James J. Dickson

Mr. B. C. Pyle

Mr. D. A. Pask

Mr. A. D. Thomson

Mr. F. M. Mullery

Mr. D. Major, as assistant chief engineer of the X-ray department of the AEI instrumentation division. A college apprentice in 1948, Mr. Major has since worked in the high voltage laboratory of the company's research department and then in the linear accelerator section of the scientific apparatus engineering department.

Air Vice-Marshal J. G. Elton, former Chief of Staff to the Chairman, British Joint Services Mission, Washington, as assistant to the managing director of C.R.E.I. (London), International Division of the Capitol Radio Engineering Institute, Washington, D.C. C.R.E.I. conduct home study courses in nuclear engineering technology and electronics.

Mr. E. Heys, formerly assistant manager, AEI computer sales, and acting assistant manager, servo sales, as manager of the electronic sales department (Manchester) of the AEI electronics apparatus division.

Mr. R. A. Nisbet, group controller, Dewhurst and Partners, southern region, as regional manager.

Mr. A. H. Campbell, general manager and a director of Hilger and Watts, as joint managing director with **Mr. G. A. Whipple.**

Mr. J. L. Thompson, general manager and a director of Square D, as managing director.

Mr. K. J. Bush, as assistant sales manager, Cambridge Instrument Company, mechanical thermometer division.

Mr. H. R. Brooker, general sales manager of Johnson, Matthey and Co., as a joint managing director.

Mr. J. A. V. Watson, a director of Castrol, as assistant managing director of Castrol Industrial, to take effect on January 1, 1962, and as an assistant managing director of the parent company.

Appointments—Overseas

Dr. R. L. Doan, manager of the atomic energy division, Phillips Petroleum Company, Idaho, as IAEA atomic energy planning adviser to the Turkish Government.

Mr. James J. Dickson, manager of engineering in the Allis-Chalmers nuclear power department, Washington, as assistant manager of the department. **Mr. Joseph V. Cupo,** chief design engineer, becomes manager of engineering in his place and **Mr. Joseph H. Blachly,** project director of the R-2, Sweden, 1956-58, and since 1960 project administrator of the Elk River reactor, has been appointed manager of projects.

Mr. Herman Holm, who has been atomic energy adviser to the president of the Enskilda Bank, Stockholm, and was on the World Bank Senn plant evaluation committee in 1958, as assistant general manager of General Atomic Europe, Zurich.

Dr. Giacomo Bertolotti, who will supervise the operation of the Enrico Fermi 180 MW PWR plant being built at Trino, North Italy, has been granted a U.S.AEC operator's licence. He is the first non-American to receive one for power reactor operation and during the past 12 months he has been gaining supervisory and operational experience with the Yankee reactor. He is now engaged in the preparation of an operating manual for the Italian plant, due to be completed in 1962-63.

Dr. Rudolf Keller, director of BASF, to the management board of the technical division of Degussa, and **Dr. Hans Verbeek,** as a deputy to the board. **Herr Paul Ungerer,** a deputy to the management board of the commercial division, becomes a full director.

Professor Ilmo Hela, director of the Finnish Institute of Marine Research, as chief scientist in charge of the research into the effects of radioactivity in the sea sponsored by the IAEA, the Monaco Government and the Institute of Oceanography (*Nuclear Engineering*, April, 1961).

Mr. E. M. Heap, joint managing director of York Shipley, to the board of Le Froid Industriel Brissonneau-York S.A., of Paris.

Award

Dr. Hans A. Bethe, professor of physics at Cornell University, is to receive the Enrico Fermi Award for 1961.

Retirements

Mr. W. B. Shannon, as assistant chief project engineer of the CEGB's Southern project group. Trained by William Beardmore and Co. and then for some time with Babcock and Wilcox, Mr. Shannon first entered the electricity supply industry in 1926.

Mr. J. F. Prince, as manager of the GEC Witton export sales department. Mr. Prince joined the company in 1919 and was appointed export manager in 1930.

Mr. A. B. Price, after 48 years' service with GEC. For 27 years Mr. Price was Erith branch engineer for Wales and south west England. In 1949 he became manager of the turbine division and a few years later sales manager of the Erith works.

Mr. H. W. Bennett, as sales director of the Birmingham Battery and Metal Company and after 51 years' service with the company.

Industrial Notes

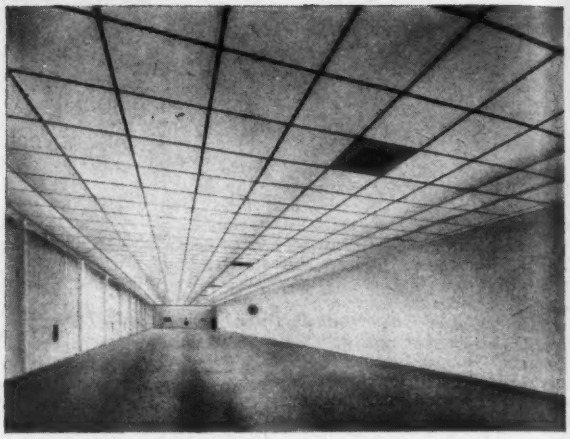
GEC, of England, and **Thompson Ramo Wooldridge**, of Los Angeles, have formed a joint British company—**International Systems Control**—for the marketing of industrial process control systems in the U.K., EFTA and the Commonwealth. The American company will provide "know-how," including computer designs, while GEC will make available relevant patents, key personnel and facilities and call upon their experience in the manufacture of precision electronic equipment. The companies have equal share capital in the project. Thompson Ramo are partners in a similar company—Compagnie Europeenne d'Automatisme Electronique—formed in France last year to meet the needs of the Common Market countries.

The Electrical Research Association's new creep of steel laboratory at Leatherhead, Surrey, was formally opened on July 7. Covering a floor area of 12 725 ft² it is a fully insulated, air conditioned, windowless building and in addition to an open working space for the creep testing machines, there are 11 cubicles for destructive testing.

The 85-company strong GKN group, proud of their new London headquarters in the Kingsway, recently opened up the building for inspection by the Press and customers. All were suitably impressed by the effect of utilitarian luxury.

Automatic Control Engineering have been awarded a contract for the design, supply and installation of the instrumentation of the Dragon project. Under the contract work is due for completion by December, 1962, and it will probably involve the expenditure of about £¼ million. Although competition for the contract was between U.K. companies only, instruments and other equipment necessary for completion of the contract will be purchased by competitive tendering among companies in the countries participating in the project.

Guaranteed £20 000 p.a. by industry and firms of consulting engineers the **Civil Engineering Research Council** has made its plans public and launched an appeal for further funds. Sums raised will be matched by grants from the DSIR. The purpose of the council, which was established in November, 1960, by the Institution of Civil Engineers, the Association of Consulting Engineers and the Federation of Civil Engineering Contractors, is to co-ordinate current research in civil engineering and initiate new projects. The initial programme is expected to cost £250 000.



Part of the 19 000 ft² clean conditions room at the Stockport (Cheshire) works of Fairey Engineering. It is to be used for assembling control rod and burst slug detection equipment for Trawsfynydd. A feature of the room is the airtight translucent ceiling supplied by Isora Illuminating Ceilings, of Slough.

A contract for the design and construction of the pond water and active effluent treatment plant for the Latina nuclear power station, Italy, has been awarded to **Nuclear Chemical Plant**, the company formed by Humphreys and Glasgow, John Thompson and the Power Gas Corporation. All effluents from this station will be concentrated to an activity level of 0·75–1·0 c/m³ and stored in a 165 m³ capacity concrete tank, sufficient to take a 6½ years' accumulation of effluent. No active waste will be released into the sea.

Tube Products, of Oldbury, Birmingham, a Tube Investment company, have been awarded a £300 000 contract for the supply of extended surface tubing for the Dungeness nuclear power station.

Electronics Associates recently opened a computing centre at their Burgess Hill (Sussex) works, the fourth to be put into operation by the organization. Others are in New Jersey, Los Angeles and Brussels.

Seventy companies exhibited at the sixth international instrument show organized by **B. and K. Laboratories** at their Tilney Street, London, headquarters, June 19-23.

C. A. Parsons and Company have opened a new mechanical research laboratory at their Heaton works, Newcastle upon Tyne.

English Electric have formed a welding equipment division for co-ordinating the company's welding business. Headquarters are at Accrington and manager of the division is Mr. R. H. Broughton (see "Personal").

Theme of the corrosion summer school to be held by the **Battersea College of Technology** in co-operation with the Society of Chemical Industry, September 25-28, is "Corrosion Problems in the Electrical Power Industry." Details are obtainable from the college secretary.

AMF have been awarded a $1·6 million contract by the U.S.AEC for the design and development of an on-load charge-discharge machine suitable for use on the Candu reactor under construction at Douglas Point, Ontario. The contract is the first to be let as a part of the $5 million apportioned for development work on heavy water systems in collaboration with Canada.

General Electric of America are to build at their San Jose, California, plant a half scale model of a quarter section of a 300MW single cycle BWR for carrying out internal steam separation experiments. It will cost about $100 000 and will be adaptable for various reactor sizes and configurations.

King Gustav of Sweden recently opened new laboratories at the **Sandvik Steel Works** for carrying out work on reactor quality steel.

Some 67 200 people visited the **International Exhibition of Fire Fighting Equipment, Safety Appliances and Radiation Protection** held in Cologne at the end of June.

Babcock and Wilcox, of the U.S., are to supply 20 90% enriched fuel elements for the swimming pool reactor at Basle University, Switzerland.

The British Welding Research Association's new engineering block at Abington Hall, Cambridge, was formally opened on July 12 by Lord Mills, former Minister of Power.

By means of a solar cell device, Sir John Cockcroft formally opened on June 27 the new Texas Instruments semi-conductors factory at Bedford. Modelled on the parent plant at Dallas it covers 132 000ft², nearly seven times the size of the plant opened at Bedford in 1957 (*Nuclear Engineering*, November, 1957). Feature of the new building is its roof of inverted thin shell concrete hyperbolic paraboloids.

Technical Papers and Publications

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS

(1961 Summer Meeting, Los Angeles)

61-SA-47. Saturated Steam Reheater Applied in New Nuclear Power Station. By F. W. Gettler Jr. (Gibbs and Hill) and J. H. Potter (Stevens Institute of Technology).

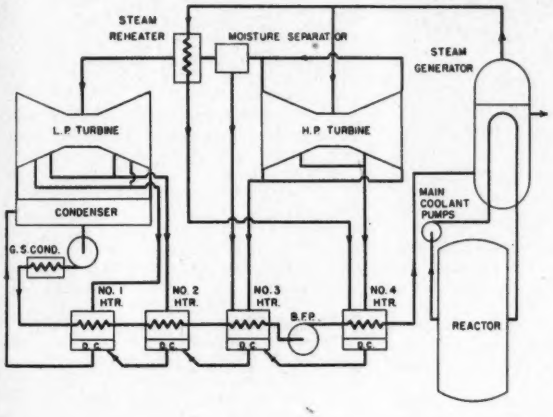
The concept of interstage reheating in a saturated steam cycle is not new, and is believed to have been first propounded for a PWR as the result of studies carried out by Lisso Mimms (1949-1952) and I. G. Stubbart (1951-1952). The present application, to the station being built by SELNI (Societa Elettronucleare Italiana) at Trino, in the Po valley, is, however, the first time that the principle has been applied in practice.

The station, which is named after Enrico Fermi, is being built for SELNI by Franco Tosi, most of the nuclear equipment being by Westinghouse. A number of different reactor systems were considered, including the use of fossil superheat; the final choice was a PWR, with an electrical output of 176 MW.

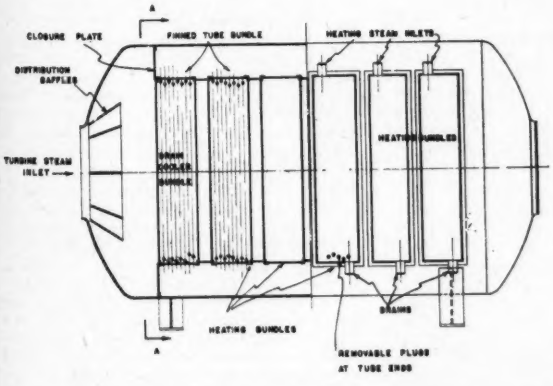
It is here unnecessary to enter into a consideration of the handicaps of saturated steam cycles, which have already been fairly fully covered in these pages (*Nuclear Engineering*, April, 1960, p. 179 and September, 1960, p. 393) and it will suffice to say that moisture separation was not considered sufficient and it was decided to reheat the steam between the low-pressure and high-pressure turbine stages with live steam, so that the l.p. steam enters at a temperature of 440°F (about 135°F of superheat.) Extensive heat balance computations were carried out on various arrangements; the results being summarized in Table 1. Cycle studies were made concurrently by Franco Tosi and SELNI in Italy, and Gibbs and Hill in New York, to decide the optimum conditions and detail requirements.

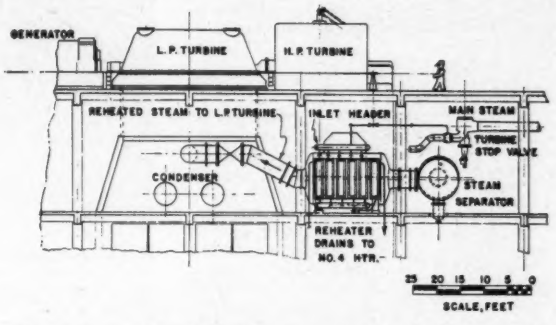
Table I. Heat balance computations for SELNI plant

Cycle	Turbine Heat rate Btu/kWh	Cycle Efficiency %
Base Cycle; no separator or reheater	13 384	25.49
Separator added; no reheat	13 275	25.71
Reheat to 440°F ..	12 336	27.66
3 feed heaters, separator, no reheat ..	11 631	29.34
4 feed heaters, separator, no reheat ..	11 551	29.55
4 feed heaters, separator, reheat to 430°F	11 296	30.21
4 feed heaters, separator, reheat to 440°F	11 270	30.28

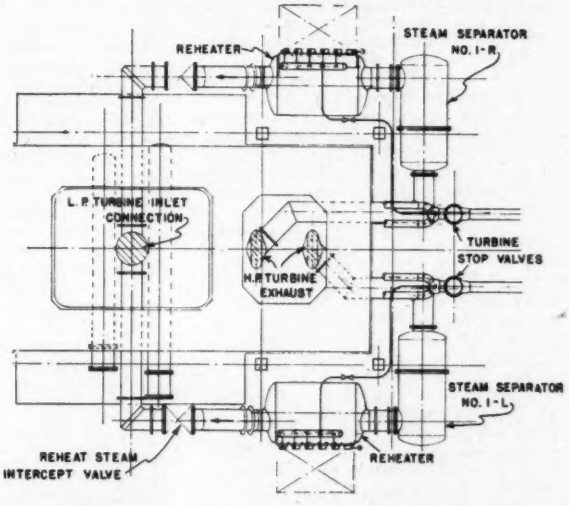


Above : Flow diagram of the SELNI station. Below : Section of steam reheater.





Above and below : Elevation and plan of steam plant, showing arrangement of reheaters between h.p. and l.p. turbines.



Practical Details

Requirements included a high performance of the reheater, with close temperature approaches, low pressure drop, and economical costs. In addition, the problem of turbine overspeed protection necessitated a low volume; the need to locate the unit near the turbine also required minimum overall dimensions.

Since the turbine is a double-flow machine, it was decided to use two half-size units, one in each cross-under connection. Intercept valves (45 in) are provided between each reheater and the l.p. turbine, to prevent overspeed on loss of load; it is not anticipated that the overspeed problems will be more difficult than with a non-reheat unit.

Each reheater has a carbon steel shell 10 ft 4 in i.d., × 19 ft 6 in long, with axial steam flow. There are six banks of tubes in cross flow, the first bank constituting the drain cooling section, while the remaining

five banks are arranged as heating sections, connected to common inlet and drain headers. The total surface of the two units is 133 900 ft².

Extended-surface tubing is used throughout. The tubes themselves are 1 in o.d., with a wall thickness of 16 BWG (0·065 in) drawn from 70/30 cupro-nickel. A helical groove is ploughed along the tube at a pitch of 10/in, and aluminium strip with a thickness of 28 BWG (0·014 in) is wound on under tension and subsequently bonded by a rolling operation. The total diameter over the fin is 2 in.

Performance

Although some 7% of the throttle steam will be diverted from useful work, the net cost per unit is reduced by the improved cycle efficiency. This takes no account of the increased life-expectancy of the turbine due to reduction in blade erosion.

The tubular elements of the reheaters are being manufactured by the Griscom Russell Company (U.S.A.) while the shells are being manufactured by the Franco Tosi organization, who are also constructing the turbine, condenser, and moisture separators, under licence from Westinghouse Electric Company, manufacturers of the reactor and steam generators.

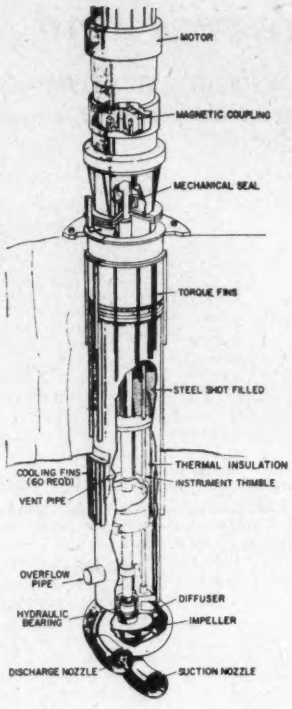
61-SA-39. Design and Testing of Sodium Pumps for the Hallam Nuclear Power Facility. By R. E. Ball and D. E. Cullman (Byron-Jackson Division, Borg-Warner Corporation) and R. W. Atz (Atomics International).

The Hallam Nuclear Power Facility has three primary and three secondary sodium pumps all designed for a flow rate of 7 200 gal/min against 160 ft head at 835 rev/min; there is a slight difference in the operating temperatures, the primary sodium temperature being 1 000°F, while the secondary temperature is 900°F. All pumps are of the vertical-shaft centrifugal type with spherical housings specially strengthened to resist pipe reactions upon change of temperature, and all pumps have the impeller, diffuser, lower bearing, etc., mounted on a cylindrical inner barrel so that, if required, the complete internals could be removed for maintenance without emptying the sodium from the circuit. The upper 6 ft of the inner barrel is filled with steel shot to act as a shield plug. The lower bearing is a hydrostatic radial type, immersed in the sodium, the upper bearing (14 ft 6 in above the lower) is a ball-type combined thrust and radial unit, lubricated by oil.

Choice of Drive

Inert gas at about 2 psi is maintained by the reactor gas blanketing system above the surface of the sodium, and possibly the most interesting feature of the paper is a consideration of different types of drive which, in addition to variable-speed operation, would give complete gas containment. As, on the primary circuit anyway, the gas will be radioactive, no leakage can be tolerated. A normal speed of 900 rev/min was chosen rather than 1 200; since the shaft diameter was settled by critical speed rather than torque, this resulted in a smaller shaft for the lower speed. Six different arrangements were considered.

1. Canned motor and eddy-current coupling. This would eliminate sealing, but would require a large heat exchanger for cooling since motor and coupling losses would be in the region of 60 kW. There would be a possibility of sodium vapour condensing at undesirable locations.



Cutaway view of primary sodium pump.

2. Open motor and open stationary-field eddy-current coupling, with mechanical seal. This would simplify drive, but introduce the problem of oil leakage from the seal into the sodium.

3. Generally as 2, but with oil-cooled coupling. This would eliminate noise problems of the air-cooled coupling, but would require additional oil-coolers.

4. Generally as 2, but with rotating-field air-cooled coupling. This would require additional slip-rings, etc.

5. Open motor, with stationary-field canned coupling. This eliminated the gas-cooling problem in (1) but the design was new and untried.

6. Canned motor with variable-frequency drive. This would be much simpler to cool, and would considerably simplify construction, but necessitated motor-generators with additional cost, losses, and space requirements.

Relative costs of the six different methods were (1) 119%; (2) 100%; (3) 101%; (4) 94%; (5) 102%; (6) 123%.

The final selection was (2), with open motor and coupling and rotating mechanical seal, for both primary and secondary pumps. It was initially expected that a mechanical seal would not be desirable for primary service, on account of the elaborate oil-leakage sumps required and the need for absolute containment of the gas. Prototype test showed practically zero leakage, however, and the cost saving over the canned motor and coupling arrangement was about $18 000 per unit. The seal used is a double unit, the thrust ball race being located between the two, and oil is circulated at 25 psi by a gear pump, this pressure being sufficient to withstand surges in the reactor gas pressure. Oil leakage is expected to be about 3 gal/year, and the leakage from the lower seal is isolated from the sodium by two sumps capable of receiving all the oil in the system. Dry-type seals are under development, but proved reliability has not yet been achieved.

Satisfactory results have been obtained on proof tests of these pumps under working conditions.

61-SA-41. Design of Reliable and Economical Heat Exchangers for High Temperature Sodium Service. By Roy D. Seifert and Laurence E. Phillips (Alco Products Inc.).

This paper gives a brief account of part of the U.S. AEC-sponsored research programme on sodium-cooled components, towards cheapness and reliability. It reviews the development on an intermediate (sodium/sodium) heat exchanger for 1 200°F service and a steam generator for 2 500 psi, 1 050°F service, including design criteria and materials and chemical investigation, with a brief summary of key features in the design.

Intermediate Heat Exchanger

Many interesting ideas are discussed. For the intermediate heat exchanger, a design has been evolved using a straight cylindrical shell with fixed tube plates, expansion being accommodated by the use of " sine wave " tubes, i.e., tubes which for some 4 ft of their length have a sinusoidal offset of some 10 in with a second offset to permit nesting of the tubes around a tube circle. Each tube can lengthen or shorten as required, without causing stressing of the tube plate or the shell structure.

Another idea which appears to have possibilities is to perform a trepanning operation on the tube plates so that each tube hole is surrounded by a $\frac{1}{4}$ in " riser " which, by minimizing temperature gradients between tube and riser, reduces stress concentration at the welds, and tends to eliminate troubles due to the tube contracting faster than the tube plate with sudden falls in sodium temperature.

Steam Generator

The first design of steam generator consisted of three units, boiler, drum and superheater, all combined in a straight-line formation, the " drum " being spherical and situated between the boiler and superheater sections, with the feedwater passing over a perforated plate and being heated by steam passing from the boiler to the superheater. This concept was later abandoned in favour of a once-through type; it was considered that, if the construction of the steam generator was similar to the IHX, major savings in tool and fabrication costs could be made.

Steam generator design throughout was based on simple sodium-water heat exchange, without double-wall construction or " third fluid " barrier. The selection of materials was, therefore, far from simple, since a sodium leak would form hydroxide which, on the steam side, would rapidly spread and cause caustic cracking if austenitic stainless steels were used. It was considered that, particularly for the superheater section, a bimetallic construction would be necessary, using AISI type 316 stainless steel for structural requirements and sodium exposure, and cladding with another material for the steam side. An extensive investigation was carried out and the most promising results appear to be obtained with Inconel cladding. Mechanically-bonded tubes were tried out, but difficulty was found in expanding them into the tube plate; the more expensive metallurgically-bonded (hot extrusion) tubes are more satisfactory. Work is also proceeding on a modified $2\frac{1}{4}$% Cr-1% Mo alloy steel with high-temperature properties similar to type 316 stainless steel; this is an experimental alloy and requires heat treatment to develop optimum mechanical properties.

Processes and Equipment

For further information on any item please enter the relevant number on the Reader Service Card enclosed with this issue and forward the card to the address given.

Consistent Welding Quality by "Orbital" Technique

Welding of end fittings to small-diameter tubes is frequently preferred to brazing, particularly where high temperatures and/or corrosive materials are a feature of working conditions. Manual welding, however, usually gives an uneven bead contour, with stop/start craters at frequent intervals, no matter how highly skilled the operator. This unevenness, particularly in the case of small tubes, forms a focal point for stress patterns which could have serious results in tubes subject to cyclic stressing from temperature and pressure variations, vibration, etc.

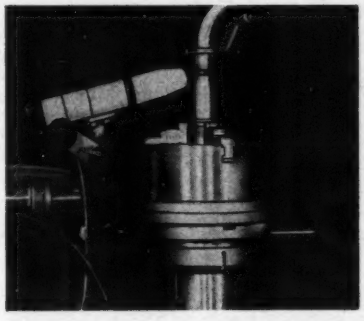
While it would be a comparatively simple matter to arrange automatic welding by rotation of the joint, using a fixed arc, this method is not practicable where the tube is bent to a more or less complicated shape before welding, as is frequently necessary where a high degree of dimensional accuracy is involved and where discard lengths are required at the ends of the tubes to prevent flattening during bending. The practical difficulties of rotating an argon-arc head around the weld have been solved by Palmer Aero Products, Ltd. (a BTR subsidiary) in the development of their " Orbital " precision automatic welding technique.

(Right) Close-up view o welding torch and tube fixture (argon shield removed).

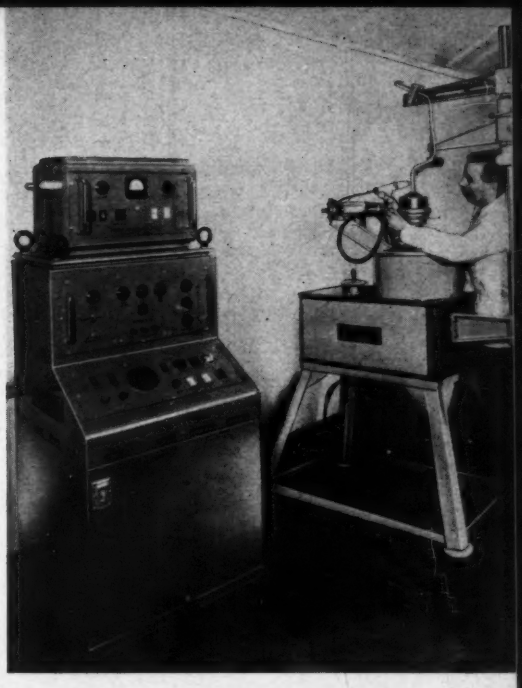
(Left) Unretouched photograph of weld between stainless steel tube and swaged-down end fitting, showing uniformity of weld.

The general arrangement of the machine can be gathered from the illustrations. The end fitting is held in a suitable fixture (a 3-jaw s.c. chuck being convenient) mounted on a rising and falling pillar, while the tube assembly is mounted in an adjustable jig, solidly supported from the main framework; a drilled copper plug at the lower end supplies a small stream of gas mixture to the inside of the joint. Argon is also supplied in the usual manner from the welding head; a semi-circular shield (removed in the illustration to show the weld) prevents excessive escape of argon and " blankets " the weld. The arc length is controlled by a low-inertia motor, responding to the arc voltage, to ensure absolute uniformity of weld.

The normal welding cycle consists of a couple of revolutions with the arc switched off, for purging purposes, two revolutions actually welding (two rapid passes have been found to give better penetration than a single slow pass) and final purging passes. The entire welding operation takes only some seven seconds.



The electronic control unit gives, in addition to automatic control over gas flow, arc length, arc striking, etc., any desired variation in current surge at starting, rate of arc decay, etc. After the most suitable programme has been determined for a given operation, the controls may be covered by a shield giving access only to on-off push-buttons, so that the machine may be operated by unskilled labour.



General view of welding machine and control console.

In addition to the extremely uniform consistency of the weld, the inner surface of the bead is remarkably smooth and even, thus eliminating all tendency to cause turbulence or restriction of flow; an important consideration in small tubes.

(Palmer Aero Products, Ltd., Herga House, Vincent Square, London, S.W.1.)

1116

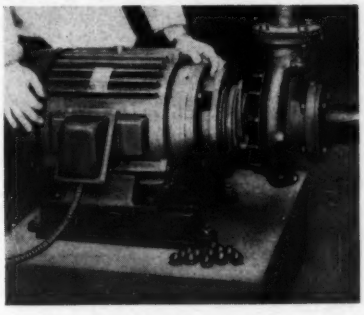
Easy-access Pump

In designing their new range of G.S. Mopumps, the manufacturers have achieved two desirable—and usually conflicting—features, minimum dimensions and ease of access for inspection and maintenance. Of the single-entry, single-impeller type, the pump is designed to fit the new compact motors to BS 2960, in which drip-proof and totally-enclosed motors are interchangeable and, by the use of a mechanical seal, shaft length is reduced to a minimum. Despite this close coupling, however, it is a simple matter to open up the pump without disconnecting pipework or lifting the motor, by removing the nuts securing the pump casing, and sliding the motor back on its rails.

Twenty-nine sizes are available, from 1 in to 5 in branch, and by the use of 2- or 4-pole motors, a range of duties is obtained up to 500 gal/min and up to total heads of 180 ft.

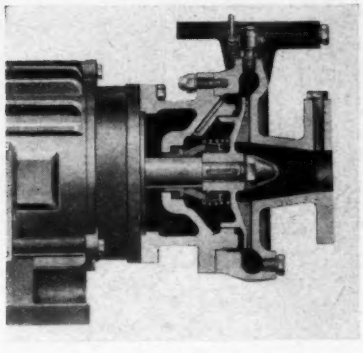
(Rhodes, Brydon & Youatt, Ltd., Reddish Engineering Works, Stockport, Cheshire.)

1117



(Above) Easy access to pump rotor by sliding motor.

(Right) Section of new G.S. Mopump.



Effluent Storage Tanks

Plastics storage tanks, with a double-skin foam-filled structure for maximum strength, are available for storage of radioactive or corrosive effluents, and several have already

Installing "Bristol" effluent tanks at AERE, Harwell.

been installed at AERE, Harwell. In addition to the chemical resistance of the material, the ability to manufacture tanks with smooth continuous faces is an advantage, since "pocketing" of effluent is avoided. Standard tanks are manufactured in capacities of 500, 750, 1 000, 1 200, 1 600, and 2 400 gallons, the external dimensions of the largest tank being 14 ft 4 in × 6 ft 4 in × 5 ft high.

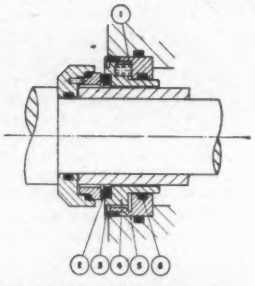
(Bristol Aeroplane Plastics, Limited, Filton House, Bristol.)

1118

Compact Mechanical Seal

The Type DD Flexibox seal is designed for high-speed shaft sealing where axial space is limited, and is suitable for operation at peripheral speeds up to 15 000 ft/min, pressures up to 1 000 psi and temperatures up to 500°F (260°C).

The general arrangement is shown in the accompanying diagram. Pressure on the



The Flexibox DD mechanical seal. 1, springs; 2, stationary seal ring insert; 3, housing cap; 4, stationary seal ring body; 5, seal housing; 6, stationary seal packing.

rubbing seal (2) is provided by a number of small compression springs (1) arranged round the flange of the stationary seal ring body (4), giving uniformity of contact pressure. Three variations on the basic design are available; with O-rings (as shown), with chevron packing, and with "reverse balance"; each type can be obtained in two ranges of axial tolerance and three face loadings. Standard sizes are ¼ in to 8 in shaft; larger diameters can be manufactured.

(Flexibox, Ltd., Nash Road, Trafford Park, Manchester, 17.)

1119

Improved Roll Filter

Improvements in design and reduced costs are announced for the Vokes Mark II "Autoroll" automatic air filter, in which the medium is accommodated in roll form and moved on as required to replace the loaded

The Vokes Mk. II "Autoroll" filter unit. (Operating mechanism may be either clean or dirty side, as required.)

area with fresh filter surface, the roll being disposable when all the surface has been used.

Motor-operated, the unit may be arranged for timer control, or the medium may be advanced by the increase of pressure differential above predetermined limits; normally 0·35-0·45 in w.g. Hand operation may be supplied if desired. The medium is a fire-resistant fibrous mat, backed by a strong muslin on the clean side, and impregnated with a stabilized wetting fluid before spooling; rolls of standard density are usually 125 ft long.

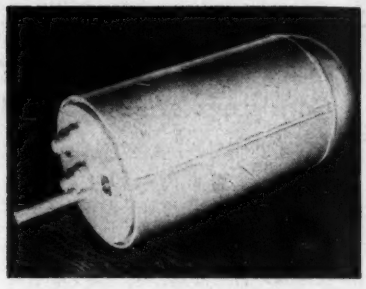
Standard widths of filter are 3, 4, 5 and 6 ft; heights may vary in increments of 6 in from 6-15 ft.

(Vokes, Ltd., Henley Park, Guildford, Surrey.)

1120

New Ionization Chamber

The new Plessey PNI 1091 ionization chamber developed by AERE, Harwell, will give a flat response to gamma radiation



The Plessey PNI 1091 ionization chamber.

down to energy levels of about 100 keV, when used with a mixed argon-nitrogen filling. It can also be filled to provide

BRIEFLY . . .

New developments in PTFE (polytetrafluorethylene) are announced by **Richard Klinger, Ltd.**, Klingerit Works, Sidcup, Kent, with the production of fine monofilament 0·007 in diameter, which can be woven or knitted into mesh form, for filters and the like where the ability to withstand temperatures up to 300°C (573°F) and the almost complete chemical inertness of PTFE are advantages. The smallest size previously generally available was 0·05 in rod. **B272**

PTFE, in the form of Teflon is being used in a new composite sealing ring manufactured by the **Pall Corporation**, 30 Sea Cliff Avenue, Glen Cove, New York. The new two-stage seal consists of a V-ring of Armco 17-4PH stainless steel, backing a ring insert of Teflon, and the operating conditions are given as −65°F to 600°F, with pressures of up to 10 000 psi. The unit is re-usable. **B273**

CRC2.26, an anti-moisture and anti-corrosion treatment for electrical and electronic equipment, which will disperse moisture from pores, cracks, or holes, has been developed in the U.S. by Corrosion Reaction Consultants, of Philadelphia. It is distributed in the U.K. in aerosol dispensers, or 1- and 5-gallon cans and 55-gallon drums, by **Hellerman, Ltd.**, Gatwick Road, Crawley, Sussex. **B274**

An image amplifier system, enabling continuous observation (via optical or close-circuit TV systems) of gamma-ray radiography from a Co^{60} source, is announced by the Zenith Radio Corporation of America, whose London agents are the **United Mercantile Co., Ltd.**, Sovereign House, Queen Street, Mayfair, London, W.1. **B275**

The Arcotron, a cold-cathode type of thyraron tube has been developed by Cerberus A.G., of Switzerland, whose British agents are **Walmore Electronics, Ltd.**, 11-15 Betterton Street, Drury Lane, London, W.C.2. Ranges at present available are 3A for 220, 380 and 500 V, and 6A at 380 V. **B276**

Elcontrol, Ltd., Wilbury Way, Hitchin, Herts, announce the development of their level control systems for conducting liquids, in multiple units for centralized operation. Standard units are available for centralized control of 2, 4, 6, 8, 10 and 12 sets of levels. **B277**

Improvements in their range of h.f. generators for induction heating purposes are announced by **Wild-Barfield Electric Furnaces, Ltd.**, Elecfurn Works, Otterspool Way, Watford By-pass, Watford, Herts. The new sets have continuous outputs to BS 1799 of 18, 27, 36 and 45 kW; the three smaller units can all be converted to 45 kW on site, if required. Multi-station switching with multiple timers can be supplied and load rematching during the heating cycle is possible. **B278**

Elimination of welding fumes and improved slag detachability are claimed for the new "Ruby" range of mild steel welding electrodes introduced by **Cooper and Turner, Ltd.**, Vulcan Road, Sheffield, 9. Available in 10 sizes, from 16 SWG to ⅜ in, the electrodes are designated E.217 on the BS 1719 scale (E.6012 on the AWS-ASTM scale) and are primarily intended for fast high-quality downhand welding. Mechanical properties are: yield point 24/28 and UTS of 29/34 ton/in², with an Izod value of 50/70 ft lb. **B279**

The data plotting table, manufactured by **Bryans Aeroquipment, Ltd.**, 1 and 15 Willow Lane, Mitcham, Surrey, can now be fitted with a symbol printer, to enable curves to be plotted in any of six symbols to enable easy identification of several curves plotted on one chart. **B280**

Stanton Instruments, Ltd., 119 Oxford Street, London, W.1, announce a new "Massflow" thermobalance for the examination of materials in furnaces, providing a continuous record of change of weight as a function of time and temperature. The pressure range in which the new units will function is from 10^{-4}mmHg to 700 g/cm² (10 psi). **B281**

Lewis Berger (Great Britain), Ltd., Berger House, Berkeley Square, London, W.1, have released details of their new two-pack solventless epoxy resin coating for steel and concrete. Suitable for brush or spray application, this material gives resistance to severe chemical attack, and can be applied, when necessary, in films as thick as 0·02 in in a single application. It is being used on the reactor floors at Bradwell. **B282**

A system for remote indication and recording from conventional process instruments is announced by the Process Control Group of **Rotax, Ltd.**, Chase Road, London, N.W.10. The basis of the system is a simple converter which can be fitted to pressure gauges and similar instruments without appreciable loading of the movement, to give digital transmission from the pointer movement. The equipment is suitable for P.O. line transmission. **B283**

approximate tissue equivalence to fast neutrons over a wide energy range; a variety of filling gases can be supplied up to 20 atm pressure.

Sensitivity with 20 atm argon filling is 1·3 x 10^{-6} A/r h; with 20 atm mixed filling it is 7·7 x 10^{-9} A/r h; maximum polarizing potential is 3 kV. The sensitive volume is 5 litres, and the overall dimensions 7 9/32 in (185 mm) diameter x 19 in (483 mm) long; weight 21·4 lb (9·7 kg). Ceramic insulators and ceramic-metal seals give robust construction; rigid electrode structure gives low microphony.

(Plessey Nucleonics, Ltd., Weedon Road, Northampton.)

1121

Mobile Crane

Difficult site lifting should be facilitated by what is claimed to be the world's largest diesel-electric mobile crane, the Coles "Valiant." An 8-wheel (4-wheel drive) chassis with

The Coles "Valiant" which can lift 55 ton with a 50 ft jib, and can be fitted with jibs as long as 240 ft.

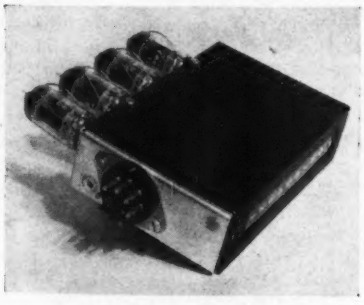
power steering and propelled by a Rolls-Royce diesel, a separate A.E.C. diesel being used for crane movements. The crane, which has 360° slewing may be fitted with jibs from 50 ft to 240 ft (with 40 ft fly jib) in length. Lifting capacities vary from 55 ton at 12 ft radius with a 50 ft jib to 6 ton at 40 ft radius, with a 200 ft jib or 1¼ ton at 100 ft radius.

(Steels Engineering Products, Ltd., Crown Works, Sunderland.)

1122

High Speed Decade Counter

Decade counters capable of operation at a count rate of 40 000 pulses/s are announced by Winston Electronics. The unit consists of a rectangular module giving a 0—9 illuminated display (figures 7/32 in (2 mm) high) connecting with its associated



The new Winston decade counter.

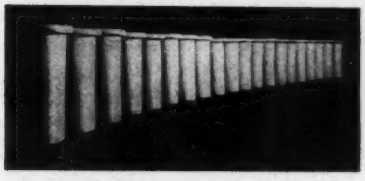
circuits through a standard octal plug. Any number of units are used in cascade to provide the necessary total counting capacity; on cessation of pulsing, the display reached with the last count is held until deliberately reset. Input requirements are a negative pulse of 50-150V, a minimum pulse width of 0·5 μs, and a maximum rise time of 1·5 μs.

(Winston Electronics, Ltd., Shepperton, Middlesex.)

1123

Porous Plastics Filters

Vyon, a porous plastics material produced from high-density Ziegler-type polythene, is being used in "candles" for filters at the



Above:—Vyon filter units for Windscale.
Right:—The Micro H additive feeder.

Windscale works of the U.K.AEA. In addition to the traditional inertness of polythene to the action of most corrosive liquids, the material has the advantage of a complete absence of detachable fibres, and is easily machined and fabricated. The effective pore size is about 50 μm.

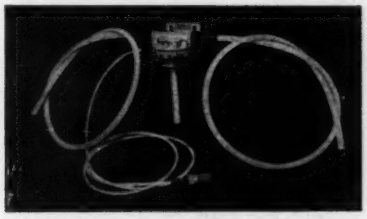
The filter units for Windscale vary from 6 in to 18 in long, and from 1½ in to 5 in diameter. Fabrication is by butt welding.

(Porous Plastics, Ltd., Dagenham Dock, Essex.)

1124

Flow Line Additive Feeder

Developed in the U.S., the FP Micro H chemical feeder is now available in Britain, and provides a method of adding controlled small amounts of chemical solutions to a



flow line, for such purposes as water treatment, rust and slime control, chlorination and defoaming.

Constructed in plastics for corrosion resistance, the unit consists of an ejector unit, with an associated differential pressure regulator which maintains an accurately metered flow of additive at the preset rate.

(Fischer and Porter, Ltd., Salterton Trading Estate, Workington, Cumberland.)

1125

CATALOGUES

Two new leaflets from **Head Wrightson Processes, Ltd.**, 20-24 Old Street, London, E.C.1, cover the Series One Cooling Tower and the comprehensive services available for process plant in the way of water and effluent treatment heating and cooling obtainable from the Group.

The Mistcool system for all forms of spraying is described in a new leaflet received from **C. A. Norgren, Ltd.**, Shipston-on-Stour, Warwicks.

Camrex Paints, Ltd., Camrex House, Hudson Road, Sunderland, have issued a 56-page booklet entitled "Industrial Maintenance Coatings," describing their many types and grades of paint, their application and particular properties.

"Export," a new publication, has been issued by **EMI Electronics, Ltd.**, Hayes, Middx. Each article appears in English, French, German and Spanish.

Two new publications of the Mullard Educational Service have been received from **Mullard, Ltd.**, Mullard House, Torrington Place, London, W.C.1. The first, "Simple Oscilloscope Measurements," combines two separate booklets previously published in the "Simple Measurement" series. The second booklet, No. 16 in the "Demonstrations and Experiments in Electronics" series, covers the construction of a low voltage power supply.

The "Quench Weld" process for cast iron welding is described in a leaflet received from **Eutectic Welding Alloys Co., Ltd.**, North Feltham Trading Estate, Feltham, Middx.

Aircraft Porous Media, Inc. (a subsidiary of Pall Corporation), Glen Cove, New York, N.Y., U.S.A., have issued a leaflet on their bubble-point test stand for measuring the largest hole sizes in filter elements.

"Products of the Holmes Organisation" is the title of a brochure giving some examples of the chemical engineering, gas handling and gas cleaning divisions of **W. C. Holmes and Co., Ltd.**, P.O. Box B7, Turnbridge, Huddersfield.

Leaflets received from **Lockheed Nuclear Products**, 3272 Peachtree Road, N.E., Atlanta 5, Georgia, U.S.A., cover the Model 701 linear amplifier, 4 cc ionization chamber, transistorized preamplifier and foil detectors for neutron flux measurements.

New literature received from the **Cambridge Instrument Co., Ltd.**, 13 Grosvenor Place, London, S.W.1, describes their recording counters, vapour pressure thermometers and meter for analysing dissolved oxygen in feed water.

Four leaflets from **Clayton Dewandre Co., Ltd.**, Titanic Works, Lincoln, describe "Clayton-Still" wire-wound heat exchanger tube for various applications.

Araldite jointing for drains for chemical effluent use is described in No. 220 of the Technical Notes issued by **CIBA (A.R.L.), Ltd.**, Duxford, Cambridge.

Tin-A-Lum fluxless solder for aluminium and other metals is described in a leaflet received from the Tin-A-Lum Division, **Industrial Synthetics (Overseas), Ltd.**, 64 Marlborough Grove, London, S.E.1.

Twenty-five years of manufacturing relays and automatic control apparatus is celebrated by the Silver Jubilee issue of the Londex Data Book by **Londex, Ltd.**, Anerley Works, 207 Anerley Road, London, S.E.20.

W. G. Pye and Co., Ltd., Granta Works, York Street, Cambridge, have published a 28-page brochure on gas-liquid chromatography with the new Argon Chromatograph.

W. P. Butterfield (Engineers), Ltd., P.O. Box 38, Shipley, Yorks, have issued a brochure on fabricated industrial equipment in alloys, mild steel and stainless steel. They have recently been approved by Lloyd's Register of Shipping (Land Divisions) as Class I fabricators.

"Factory Planning and Installation" is the title of a new booklet received from the F.P.I. Department of **Thos. W. Ward, Ltd.**, Albion Works, Sheffield, describing some of their achievements in the nuclear field as well as in industry in general.

Taylor Bros. and Co., Ltd., Trafford Park Steel Works, Manchester, 17, have issued a brochure on the production of rolled steel rings and circular die forgings.

"Control for Industry" is the title of a 44-page stiff-cover brochure published by **Lancashire Dynamo Electronic Products, Ltd.**, Rugeley, Staffs.

Leybold-Elliott high vacuum process plant is the subject of a brochure received from **Leybold-Elliott, Ltd.**, Manor Way, Borehamwood, Herts.

The **Clark Bros. Co.** Division of **Dresser (Great Britain), Ltd.**, 197 Knightsbridge, London, S.W.7, announces the publication of a brochure, P-100, which describes the Podbielniak line of centrifugal contactors, solvent extractors, chemical reactors, separators and clarifiers.

Orbits . . .

LOSING ONE'S JOB no longer has the sting or the stigma that it used to; with present-day amalgamation and reorganization of large and small companies it has become a normal occupational risk. In this country, however, we have never quite accustomed ourselves to the American business outlook (except for the ghastly desk-filled barracks known as Open Plan offices, which we are accepting all too readily). In some U.S. organizations, anyone below vice-president level may find himself on the street at an hour's notice and think very little of it—except to go across to a rival organization and find himself something better. Here, however, there still lingers a trace of the old-fashioned feeling that one has been weighed in the balance and found wanting, rather like the family butler with a couple of bins of port unaccountably adrift. Firing, therefore, is carried out with a reasonable amount of well-simulated regret and decent-chappery.

Or—not having been fired lately—we thought it was, until we recently heard of a case in which the only intimation of the impending decimation of a department was a list of names sent without warning to the head of the department . . . containing his own name.

To us, this seems inexcusable. It is not only bad manners, it is bad business. No company, from the smallest back-room shop to the largest organization in the world can afford to breed ill-will just for the fun of it, and many a contract has been lost because the top man with whom the decision rested was an ex-apprentice who had had a raw deal 40 years before. Good manners cost very little and often pay big dividends; bad manners raise an overdraft that never gets paid off.

Have Gen, Will Travel

Turning from the slightly depressing subject of firing, let us briefly consider the opposite aspect, the hiring of staff. The U.K. AEA spends not inconsiderable sums on advertising for Bright Young Men, but one of their more elaborate efforts (which appeared some weeks ago) took the form of a display space apparently aimed at luring the aforesaid B.Y.M. to Dounreay.

The feature which struck us most forcibly, however, was not that they should have to lure people to Dounreay (although no doubt some of these northern types will put this down to typical Sassenach prejudice—which we wouldn't be without) but the extraordinarily naïve tone of the advertisement. Sketching in the background of the fast reactor and showing rough drawings of fuel elements, they finished off by giving the impression that what they were saying was . . . "Well now, that's what the fuel elements have to do, why not come and help us to find out how to design them?"

Had this advertisement appeared in 1956, it would have been an admirable straight - from - the-shoulder-young-man-we-need-you piece of public relations. Appearing at this stage of the proceedings, at a time when the general feeling is that it's about time that the fast reactor was up to full power, the impression it gives is that everybody is still completely clueless.

Buzz

The aspect which leaves us more baffled than a steam-separator is that we heard some time ago, by grape-vine, galley-wireless, little birds or whatever, a buzz to the effect that someone *had* designed a fuel element for the fast reactor that was simple, cheap and efficient. Even if one discounts everything considerably, and merely assumes that it is relatively cheap, relatively simple, and relatively efficient, it sounds hopeful. So why advertise for amateur talent? . . . Maybe we're crazy, too.

Vintage News

News is, unfortunately, the most perishable commodity in the world, and we often look ruefully at something really interesting that comes in just too late—until a closer look-see shows that it was vintage news anyway. By the very nature of things, much of interest in the nuclear field has to be vintage—an example is a report received from the U.S. too late for our "Technical Papers" feature, which includes amongst other items, a summary of operating experience at Shippingport—with the output curve plotted up to June, 1960, thus taking the bloom of youth off for a start.

"X" Certificate?

The reason, of course, is not far to seek. A bright lad has a bright idea, which promptly takes form. By the time it has been kicked around in his own organization and passed through what used to be known as the Proper Service Channels (and what silted-up channels they are) the "onlie begetter" is wishing that he'd taken up growing tomatoes for a living . . . BUT it still has to undergo declassification—a process which makes the legendary mills of God sound like isotope centrifuges.

By a peculiar coincidence, an almost perfect example of this arrived a few days ago, in the form of an AEA report on the effect of irradiation on the graphite/CO_2 reaction—a subject in which this country could hardly be said to be uninterested. Dated 1961 on the cover, it coyly admits inside that it is the declassified version of a report originally compiled in January, 1956, on results in Bepo.

Was this report kept under wraps because it would frighten everybody? We may have drawn the wrong conclusions from some of the results (we're pretty thick sometimes) but mentally extrapolating from one curve to present-day reactor power densities would frighten us stiff, if we were contemplating designing any reactor, let alone something like the AGR. If, on the other hand, further research has shown that these results are not capable of simple extrapolation and that everything in the garden is lovely, then why publish it now?

Ship that Shouldn't . . .

Not requiring much in the way of entertainment (we've always our phonograph cylinders for a wet evening) we missed the recent TV play about the nuclear ship that couldn't be stopped without the hero (?) exposing himself to so much radiation that he practically glowed in the dark. Based on newspaper reports, and comments from colleagues who did see it, however, it would seem that the audience-reaction would be twofold. Those who had any glimmering of nuclear knowledge would have been moved to gusts of bucolic laughter; those who hadn't, would have sat down immediately and written begging that nice Mr. Marples not to allow such dangerous things to be built (not that he shows any passionate eagerness, anyway).

But why didn't they throw out the anchor and steam round in ever-decreasing circles? Were they afraid of it disappearing altogether?

". . . the pale cast of thought . . ."

In a recent speech by the Director of the U.S. AEC's Office of Industrial Participation, he quoted some remarks of Dr. Alvin Weinberg of ORNL:—

> *". . . it is easier to spend money than to spend thought . . . money is relatively plentiful but thought is still scarce . . ."*

Now Hamlet, you may recall (if, like Tangent, you have a dictionary of quotations handy) was not entirely in favour of too much thought; neither, for that matter, was Julius Caesar when he pointed out that ". . . such men are dangerous." There must be many who have a sneaking sympathy, but don't care to admit it, feeling that they are a tiny minority, adrift in a sea of eggheads. Doctor Weinberg cannot be said to endorse their conduct—but at least he shows that they are not alone.

SONG OF THE DIM-WITS

Determined our Project shall make a big splash
We're all of us feeling a bit overwrought;
Although—with our backing—we've plenty of cash
We're sadly in need of some good solid thought.

After due deliberation
And extensive meditation,
Speculation, rumination,
In despair we sink;
We have tried imagination,
Contemplation, cerebration,
Cogitation, lucubration,
BUT WE JUST CAN'T THINK!

Still — as Doctor Weinberg so forcibly tells
(In syllables clear to a half-witted oaf)
The Cash saves expending the little grey cells
For dollars are cheaper than using your loaf.

Tangent